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Science and Technology, Saviour or Destroyer?[1]

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Introduction.

Technology conjures up a slightly soiled image these days. It reminds us of industrialised cities, of pollution, of the uranium debate, of bauxite mining and wood chipping. It may trigger-off images of psychological manipulation, of drugs, and of impending fuel shortages. Many people would agree with Georges Pompidou, former French President, when he said with typical French candour: "There are three roads to ruin: women, gambling and technicians. The most pleasant is with women, the quickest is with gambling, but the surest is with technicians."

To some people science applied to technology is below par for the course and is pursued by people who are not quite able enough to make a career in pure science, though in this connection I am reminded of a statement made by Sir William Hardy to Sir Henry Tizard when he said: "You know this applied science is just as interesting as pure science, and what's more it's a damned sight more difficult."

Despite all this I am glad to be an applied scientist. I started science by accident, in the sense that at the end of 1st Year at Perth Modern School, I dropped French and took up Chemistry. My main reason for making this decision was not because I carried out chemistry experiments at home or was interested in any way in the subject, but rather that the French teacher continually made jokes about my pronunciation of the language. However, once the decision was made I was irrevocably destined for a career in science. And as I recall it, my father (who was of French extraction and held a Master of Arts degree) encouraged me to do science because he believed that the future lay with science and not the Arts.

To my great surprise I enjoyed my chemistry lessons enormously. Our teacher was the school's Art teacher who was fascinated by colours. Much of our course was taken up in manufacturing chemicals which possessed the most beautiful colours. But I do not consider that year was wasted. We may not have learnt a lot of chemistry, but we did learn that science is concerned with beauty and is intimately related to the real world. Perhaps because of this background I have never agreed with C. P. Snow's Two Culture thesis, for my experience indicates: that scientists have a sense of wonder at the majesty of nature; that they are people with a sense of history and an affinity for the past; that a significant number have a deep love of music and art, and that they possess an innate curiosity and concern for the world in which they live—and that science is *not* just a storehouse of facts to be used for material purposes, but is one of the great human endeavours which ranks with religion and arts as one of man's quests for truth.

Unfortunately the world has lost the capacity to wonder. We have lost the childhood-like innocence of an Isaac Newton, who described himself as a boy playing by the sea shore and being fortunate enough to find prettier shells than the ordinary, whilst the great ocean of truth lay undiscovered before him. Well, I guess we have now discovered many of the pebbles and sea shells. We have seen the "Whizz Bang" discoveries of the scientists, we have watched the astronauts on the moon and learnt to accept the modern computer as a part of our everyday life. In a sense, like Robert Oppenheimer's nuclear physicists, we all *know* science and technology, and have, to a certain extent, lost our experience to wonder.

The modern day disenchantment of Science and Technology is part of a disenchantment with ourselves, with our achievements and our failures. We have failed as people, as communities and as nations. We have climbed our mountains and found that the achievement is less satisfying than the achieving. In our disenchantment we have attacked the prophets who promised us salvation, and certainly, Science and Technology are there to take a share of the blame.

But it is misleading to point the finger at Science and Technology—the tool. We should look for a moment at the users of the tool and not delude ourselves into believing that by destroying the tools, we have in some miraculous way changed the users.

[1] Read at an evening meeting held at the University of Western Australia on 24 April 1978 as part of a symposium entitled "What is Science?" organised by the Royal Society and the University of Western Australia Extension Service.

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The Saviour of Mankind?

In 1930 Richard Gregory, who at that time was Editor of *Nature* made the following statement: "My grandfather preached the Gospel of Jesus Christ. My father preached the Gospel of Socialism. I preach the Gospel of Science."

Well, not many people believe in Saviours anymore! M. Lefeaux on one occasion confided to Talleyrand his disappointment at the ill success with which he had met in his attempt to bring into vogue a new religion which he regarded as an improvement on Christianity. He explained that despite all the efforts by himself and his supporters, his propaganda made no headway. He asked Talleyrand's advice as to what he should do. Talleyrand, the Statesman Bishop who became a leader of the French Revolution and later Prime Minister of France, replied that it was indeed difficult to found a new religion, so difficult that he hardly knew what to advise. "Still", he said after a moment's reflection "there is one plan which you might at least try. I suggest that you be crucified, and rise again on the third day." The record does not indicate if Lefeaux accepted Talleyrand's advice, but I suspect that he declined.

The emergence of modern society, beginning in the 16th Century, marked the beginning of a period of great optimism about science. The new science, based on observation and experiment, was to be a liberating force for humanity. Francis Bacon, in many ways the midwife of the scientific revolution in the United Kingdom, said: "the truth and lawful goal of the sciences is none other than this, that human life be endowed with new discoveries and powers."

In his Utopian work "New Atlantis", Bacon described a society in which science was dedicated to increasing the welfare and benefits to humanity. Science was to multiply human enjoyments and mitigate human sufferings. By controlling nature it was hoped that science could bring relief from hunger, disease and drudgery in an age which has been described by Hobbes as "nasty, brutish and short."

Since those days science has become a dominant force in our society. Advances in medicine *have* reduced disease and increased our life expectancy. The green revolution *has* provided new hope in the battle against hunger. Transport and communication developments have brought the peoples of the world closer together. The Apollo flights have revealed the fragility of our "spaceship Earth", and astronomical discoveries have given man a new perspective on his place in the Universe.

The tremendous impact of science on civilization springs for the most part from the numberless practical applications of scientific knowledge. Technology, or the art of contriving things and situations to man's advantage, is as ancient as conscious man himself. It has thrived in various forms and to various degrees in all civilizations. Pre-scientific technology, however, resulted by and large from trial and error gropings and human ingenuity. It was not based on much understanding of the principles on which the contrivance worked.

To most people the link between the abstrusities of science and the wonder of modern life is technology—seen as tangible machines that produce goods or ease the burden of labour. Thus the goals of technology are simple; to reduce muscular effort in the fulfilment of man's daily needs; to increase man's comforts and conveniences; and to render him collectively, as a nation, powerful enough to defeat his enemies in time of war.

There would be no disagreement with the thesis that our lives are affected by Science and Technology in thousands of different ways, and that the achievements of these are all around us. But have the hopes of the new science been realised? Have we witnessed the relief of man's estate?—to use Francis Bacon's turn of phrase. Are the goals of technology worthwhile to mankind in the long term? Are Science and Technology indeed our Saviours?

To these questions a growing number of people, both scientists and non-scientists, are beginning to give ambivalent answers.

We live in a world faced with the possibility of destruction by a nuclear holocaust, a world confronted by environmental despoliation, of test-tube babies and genetic engineering, a world in which more than half the population faces some form of malnutrition and two-thirds live in poverty. Faced with such a world, many people are beginning to reassess the role of science and technology, and even the Organization for Economic Co-operation and Development (OECD) acknowledges 'a growing public disenchantment with science and technology.'

The Destroyer?

Well, if Science and Technology are not the Saviours of Mankind, are they, as the subtitle suggests, the Destroyers?

"Technology—Opium of the Intellectuals", was the title of a famous article in the New York Review of Books several years ago. In it the author argued that we in the industrialised nations had become enslaved and addicted to technology, which by providing material comforts, covered up the deeper and more important social, psychological and political shortcomings of present forms of society.

This view of technology, while by no means a majority one, has recently grown in importance, particularly in the industrialised world and especially among the young. It has led to a view that it might be a good idea to do away with technology altogether, and return to forms of society in which human and social issues once again become the main concerns.

Professor von Euler, who was awarded the Nobel Prize for his outstanding work on the role of adrenalin in stress reactions, tells a charming true-life story which illustrates how

very simple people can have the wisdom to realise that the love of your neighbours is much more likely to bring happiness, than the material gains offered by a technological society. "In a train over the Andes, between Mendoza and Santiago I sat talking to a Bolivian farmer, and asked him whether he utilised modern fertilisers to increase his harvests. 'Oh, no', he said 'that would only create dissatisfaction in my neighbours. I prefer a modest harvest so that I can remain on good terms with them'." We can respect this farmer's wisdom, because so few of us would be able to imitate him. And perhaps if we were honest with ourselves, most of us would have to admit that we like to exhibit our superiority both as individuals *and* as members of a "developed" nation.

For it seems to be a fact of life that people who are forced to live without technology quickly become unhappy with their situation when they see others benefiting from it. It is the "developing" countries (that euphemistic phrase beloved by politicians) which love the trappings of technology and exhibit their beautiful nuclear reactors supplied by the "developed" countries as exhibits of their own evolving technology.

The case against Science and Technology

The current criticism of science and technology is taking place at two levels—the material level and the philosophical level.

The attack at the material level is too well known to need elaboration. In his opening address to the Ciba Foundation's symposium on civilization and science, Hubert Bloch summarized the thesis of this attack as follows: "It lies in the contribution of science to the deterioration of our world—or rather in the uncontrolled application of scientific technology that leads to the now well-known problems of environmental pollution, the use of science for war and destruction and the social implications of the by-products and side effects of medical progress—and in the fact that science and technology have failed in many people's view to make our lives happier and more meaningful." The critique at this level thus concentrates discussion on the familiar catalogue of the ways in which science and technology have contributed to the deterioration of the human milieu.

The second kind of criticism is of a more sophisticated nature and is far more "anti-scientific" than the material level of criticism. The criticism is not so much directed at the role of science in contemporary society but at the oppressive nature of the scientific method itself. It is argued that science dominates modern culture to such an extent that we have come to accept that the only experiences which are real are those that can be confirmed scientifically and be given an independent, objective existence. Thus our senses, it is argued, are no longer allowed to provide us with an experiential approach to life.

Can all human emotion and experience be reduced ultimately to a page of mathematical symbols?—it is asked. Can thought really be explained in terms of physical and chemical reactions? Can we discover the possibilities of ourselves and our world solely through the exploration of this form of consciousness? Those who would answer "no" to these questions believe that our all-encompassing faith in the scientific mode of consciousness has become oppressive, because it shuts us off from the real world of experience.

The historian Theodore Roszak in his book "Where the Wasteland Ends" makes a typical assault on the myth of scientific objectivity. The problem which Roszak has raised is that of the relationship between the objective world "out there" and the subjective world "in here", between rationality and romanticism, between intellect and emotion. Roszack's writings represent the hippy, flower-power subculture. He claims that the scientific mentality is intrinsically alienating.

Scholars such as Everett Mendelsohn, Lewis Mumford and Herbert Marcuse claim that modern science, rather than being a Saviour, is a false God that must itself be destroyed lest the scientific method inevitably lead to a dehumanised society, and possibly even to total destruction.

Outlook for the future

Professor F. R. Jevons, Vice-Chancellor of Deakin University and formerly Professor of Liberal Studies in Science at Manchester, gave a lecture at W.A.I.T. last year in the "Science, Technology and Public Policy" Lecture Series. He pointed out that in times when public opinion has swung away from science it is all the more important to use science and technology to best advantage. He pointed out that if one speaks about alternative systems we are really talking about alternatives *within* the science knowledge system, not alternatives *to* it. Those who argue for a return to Nature, are not *really* talking about a return to a mode of living which involves cholera, typhoid and leprosy; they are talking about a controlled Nature, in which science must still play a role.

A concern with the environment, with the quality of life, means an increasing need for applied science and technology, and in the long run, for more pure science as well. We want to create, for example, incentives for the development of more modest technologies less intrusive as far as the environment and the human individual is concerned. Technologies like this could be doing some of the necessary industrial tasks that are performed today by technologies that are too much of a nuisance. We want to create incentives for the development of counter-technologies in order to repair, where it is reversible, the damage that technology has done.

We want to create attractive employment for people whose work has to be curtailed or abandoned because it is too destructive or too unpleasant for the rest of us. In short, we need a great deal of science and technology in order to provide a much longer menu of possibilities from which society can select the few tasty and nutritious dishes that are indicated by the technology assessment process. We want to feel free to do research on and sometimes to develop or even to bring into the prototype or initial production phase, technologies that we can then renounce as inappropriate on total human appraisal.

What is required is the joint effort of people from many disciplines. Not only the science disciplines but also the social sciences and those who understand the social process. We need to learn much more about the nature of science and technology, of the relationships between them and their impact on social evolution. Human societies are more complex than we once imagined and every intervention has unforseen results.

More power has not made us wiser or more considerate. Only a better understanding of society coupled with a new appreciation of the role of science and technology can determine our future.

Society has demanded better transport, better communications, better drugs and medicines—and science and technology has supplied them. Yet it is only in recent years that we have realised that man is not satisfied by bread alone, that an abundance of material things do not satisfy the human soul. Life requires a sense of purpose if it is to have meaning, and perhaps the aims of technology as perceived by society and listed earlier in this lecture, need re-examination. I think society is in much the same situation as was Cardinal Wolsey in Shakespeare's 'King Henry VIII', when he said: "If I had served my God with half the zeal I served my King, he would not in my age have left me naked to my enemies." And perhaps if we had spent half as much time and effort in seeking to make men brothers as we have in producing material things, then we may not have found ourselves in our present situation.

Robert Pirzig's novel "Zen and the Art of Motorcycle Maintenance" is devoted to problems of the split in our culture, and in our ideas of intellectual and emotional reality. Pirzig argues that: "A motor cycle functions entirely in accordance with the laws of reason, and a study of the art of motorcycle maintenance is really a miniature study of the art of rationality itself." He also believes that: "The Buddha, the Godhead, resides just as comfortably in the circuits of a digital computer or the gears of a cycle transmission as he does at the top of a mountain or in the petals of a flower." Pirzig believes that the way to solve the conflict between human values and technological needs is not to run away from technology, but to break down the barriers of dualist thought that prevent a real understanding of the nature of technology. Technology is not an exploitation of nature, but a fusion of nature and the human spirit into a new kind of creation that transcends both.

The intellectual leadership of the 20th Century rests with scientists, and as Jacob Bronowski has pointed out, that poses a grave problem because science is a source of power that walks close to Government and that the State wants to harness. This is of concern because the very rigour of their training sometimes allows scientists to be manipulated by men wise in political ways. But if science allows itself to be used in this way, the beliefs of the 20th Century will fall to pieces in cynicism.

For some time we, as citizens of a technological society, have been living in a crisis of human values. Traditionally we have looked to religion for our moral and ethical guidelines, but our confidence in theology has been eroded. Science and technology have pervaded our lives and cultures to such an extent that we have been tempted to look to science itself for values. But science cannot be the sole provider of these values—in fact it is a factor in the present crisis.

It is not the business of science and technology to inherit the earth. Rather it may be that science working together with religion and philosophy, might be able to create a set of human values which will allow us to emerge from our chaotic time of transition. So perhaps Science and Technology may yet be the Saviour rather than the Destroyer of Mankind, though in a different way than we first imagined. Time alone will tell.

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Science and the Arts[1]

by D. R. C. Marsh

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When, some time last year, I accepted the invitation to talk to you this evening, April 24th seemed a comfortable time away, and I had the vague feeling that it would be easy enough to find something to say about science and the arts. In fact, when I sat down to write, the enormity of what I'd let myself in for came rushing down on me: the difficulty is not knowing where to start, but when to stop. Undoubtedly there exists an important relationship between the two main areas of human intellectual activity, and a vitally important one, tco, but one which, in the last century or so, has been characterised by misunderstanding and mistrust on both sides, and I don't mean simply in that traditional area where we compete for public funds. My credentials for talking about the subject, I had better make clear at once, are slender. Some maths, physics, chemistry, geology a great many years ago, a period as a farmer, and then a return to university to read the subject that I now profess. But by the nature of my office, since professors these days have to be administrators, negotiators, statisticians, and financial wizards, I've had a great deal to do with scientists over the last fifteen years. At the risk of sounding flippant, some of my best friends have been scientists, and I hope to retain the friendship of one or two even if they hear of tonight's talk.

First of all, I perhaps should say that I interpret the arts in my subject as not just the creative arts, but as the whole area of human knowledge, the study of men and the works of of their imagination and intelligence, taken in by the traditional Arts Faculty. But I shall talk about the creative arts first: it is surprising but true to say that the tremendous development in scientific technology has made surprisingly little difference to the creative arts. Certainly, some sculptors now work with welded metal, or epoxy resins, some painters with acrylic paints, some make patterns of light with laser beams, some musicians use strange new electronic equipment to make equally strange new sounds, but by and large the practitioners of the arts continue to use the traditional methcds. Sculptors still work with the chisel and mallet, painters with the brush, and even the most complex of new musical sounds must be translated into musical notation and written down, laboriously, by the composer. I don't propose to talk about computer-generated poems by the way. I don't believe such things exist. If we turn to science as a subject, or as an inspiration for great works of art in our own time, there is the same surprising lack of impact. The last great advances, or so they seemed then, in scientific thought, that made a decided impact on the artistic imagination were, I think, Darwin's theory of evolution, and Freud's psychological explanations of human behaviour. Confronted with $e = mc^2$, we all seem struck dumb, and Wordworth's prediction of 1801 has not come to pass. (I'm quoting from the Preface to the second edition of the Lyrical Ballads, and you might remember that Wordsworth was a very talented mathematician, and that Newton was one of his great heroes.)

> "Poetry is the first and last of all knowledge—it is as immortal as the heart of man. If the labours of Men of science should ever create any material revolution, direct or indirect, in our condition, and in the impressions we habitually receive the Poet will sleep then no more than at present; he will be ready to follow the steps of the Man of science, not only in these general indirect effects, but he will be at his side, carrying sensation into the midst of the objects of science itself. The remotest discoveries of the Chemist, the Botanist, or the Mineralogist, will be as proper objects of the Poet's art as any on which it can be employed, if the time should ever come when these things shall be familiar to us, and the relations under which they are contemplated by the followers of these respective sciences shall be manifestly and palpably material to us as enjoying and suffering beings. If the time should ever come when what is now called science, thus familiarised to men, shall be ready to put on, as it were, a form of flesh and blood, the Poet will lend his divine spirit to aid the transfiguration."

This hasn't happened, except perhaps with the ideas of Sigmund Freud, which were partly derived from art anyway. Yet in the Renaissance, that great scientific leap forward, the human imagination was fired by the ideas of discovery, and scientific images crop up everywhere, in religious poems, pastoral poems, political poems, even love poems, notably those of John Donne. Why hasn't it happened again, in spite of staggering discoveries about genetic structure, atomic energy, astonishing technical achievements, like putting men on the moon and bringing them back safely? Apart from some science fiction, much of which is really cowboys and indians in funny clothes, some programme music, there isn't much to show.

Well, if we are to believe C. P. Snow, now Lord Snow, this is because of an ever-widening split between the scientists and the rest of us, which he described in a lecture called "The Two

[1] Read at an evening meeting held at the University of Western Australia on 24 April 1978 as part of a symposium entitled "What is Science?" organised by the Royal Society and the University of Western Australia Extension Service.

Cultures". Roughly summarized, Snow's argument was that all over the West there was a regrettable lack of understanding of how scientists thought and acted, of what science really was, and that many of the people who were socially and politically important, people he thought of as fairly represented by the term literary intelligentsia, could not or would not make the effort to understand what scientists were on about. Scientists, in his opinion, tended to be more literate than non-scientists were numerate. Non-scientists (there isn't a convenient non-negative word; artists won't do, and artsmen sounds as if it has been coined by Stephen Potter) were not capable of understanding, or not inclined to try to understand even the simplest of scientific concepts. Lord Snow, who had been a scientist, and was at the time of the lecture a successful novelist, produced his thesis with an irritating air of authority, and soon found himself being quite roughly handled in the correspondence columns, earning in particular a sharp and rather unfair rebuke from the great but cantankerous English critic the late Dr F. R. Leavis. The correspondence, for those who are interested, can be found in *The Spectator* of 9 March 1962, and following numbers. But by and large, there was some truth in what Snow said, and since then, the prevailing orthodoxy, especially among scientists, is that while scientists are literate *enough*, non-scientists don't understand or appreciate what scientists are doing for them, don't sympathise with their problems, and are little better than Luddites, machine-breakers. Too many scientists, to non-scientists, appear to be efficient barbarians, and too many non-scientists, to scientists, effete dilettenti. Let me at once admit faults, and honourable exceptions, on both sides, but then go on to say that the apportioning of blame for the split is by no means as simple as Snow's thesis would have us believe. Many scientists seem to have lost the knack of communicating the essence of what they are doing, to the people for whom it is ostensibly being done. I don't underestimate the difficulty of that kind of communication, but I know it is possible. In my last university an historian, an art historian, a composer, a botanist, a zoologist and I lunched together every Tuesday. We were friends, and we *trained* each other to talk about our subjects to each other. Rather to our surprise we found that quite soon we could understand each other, provided that we all abandoned our professional jargon. And because the detail required to understand how things were done wasn't readily comprehensible to us, we found ourselves cast back much more on why questions. We were, in other words, not only talking about our interests, but trying to justify them, and it was very good for us. If one feels that nobody outside one's own group can understand what one is doing, then it is too easy to feel released from moral responsibility. And moral responsibility is most important to the sciences. I suppose it is no accident that the art in which most scientists are most interested is music. It is hard to find a moral content in music.

Not by any means always, but in my opinion, too often, scientists have retreated into their mystery, and shut the doors behind them, muttering something about objectivity and measurable fact over their shoulders as they go. But there is sometimes the impression given that they alone deal with truth, and what the rest of us, in our subjective opinionated way, do with that truth when it is handed down to us, is none of their business. This is dangerous in two ways. Firstly, because any habitual assumption of superiority is corrupting to the holder, and secondly because if the authority is august enough, the rest of us are too easily overawed, and sometimes don't have the temerity to enter a debate where we might have useful contributions to make—whether the Third World really needs nuclear technology, for example, is something that shouldn't be decided only by nuclear physicists or nuclear engineers—or if we do enter, feel we should try to meet them on their own ground. We decide that we should import "scientific method", however we understand or misunderstand that phrase, into our own studies, and we generally come a cropper. "What can't be measured isn't serious" is a particularly insidious myth. *King Lear* is one of the most serious things I know, yet any attempt to quantify its qualities provides a very silly answer. We are all constantly concerned, in our daily lives, in our professions, with acts of individual critical judgment. To suggest that such questions are unserious, or improper, is absurd, just as it is absurd to suggest that any one discipline has a monopoly on truth, or the way to discover it.

There are many kinds of knowledge. Much is to be found in the great works of the artistic imagination, what W. B. Yeats called "monuments of unageing intellect", which only truly exist at the level of individual human response. Once one has responded to Lear's suffering, and seen him as at once an individual and as a representative of suffering humanity, one will never again be able to brush aside considerations of human suffering quite so easily. And that, too, is valuable truth.

To understand more about ourselves, the world in which we live, is an admirable aim. What we do with the increased knowledge depends on the nature of our understanding, and on our understanding of consequences. If our literary humanist culture is a jealously guarded privilege, inward-looking, and soothing in its effects, distracting us from great problems of human suffering like sickness and poverty and aggression, then we need to be shocked out of it. If scientists can through their search for knowledge help to solve these problems, then they help the human spirit to flourish. But they need the humanists, too, to make them aware of the consequences of their actions, to point out that in a potentially savage world, no discovery, in the use to which it can be put, is morally neutral. Understanding, mutual understanding, is what the world most needs, and the arts and the sciences may as well make a start by trying to understand each other.

Journal of the Royal Society of Western Australia, Vol. 61, Part 4, 1979, p. 105-108.

Science and Government

by Andrew Mensaros, M.L.A.

When you were kind enough to ask me to deliver this paper, I assumed and anticipated that you were inviting me as Andrew Mensaros and not as the Minister for Fuel and Energy. Indeed it is on that understanding that I have prepared my talk.

Since my subject is "Science and Government", I should like to take notice briefly of their history and development, their respective activities, and the role that they play in society; and in the course of this, I hope to underline their differences, but at the same time to speak of their interdependence and interaction.

Both science and government have been around for a long time—government perhaps rather longer, since in the Upper Palaeolithic, when science and learning were scarcely conceived, I have no doubt that stronger, and more ambitious cavemen were already clubbing their weaker tribesmen into submission.

In early civilisations, science was sustained by wealthy individuals, and a man who sought knowledge for its own sake needed either to be rich himself or to find a rich patron. Private patrons, however, tended to favour the arts rather than the sciences. They would sooner see their benevolence embodied in a statue or a panegyrical poem than in a theorem or an industrial process—for after all, manufacturing industry in those days was principally the concern of slaves or of freed men. If a man was not rich, and could not find a rich patron, his chances of doing scientific research were slim, for the governments of the ancient world did not generally count the patronage of learning among their functions.

In consequence, the Graeco-Roman world saw a great development of abstract science, of pure mathematics, of the kind of work that could be done by an able man on his own, or at least with comparatively little equipment and few assistants, but little or none of that kind which demands teams of workers, big buildings and bigger budgets.

It is perhaps remarkable that governmental patronage of science did not vary much with the type of government. The ancient world saw many different distributions of power in society, from the earliest patriarchal monarchy through various forms of government by the one or the few or the many, until finally the world-state of the Romans relapsed wearily into an autocracy tempered only by palace revolutions and insurrections by ambitious generals. Under all these types of rule, government funding for scientific research was a very rare occurrence. King Hiero of Syracuse presumably provided workmen and materials to help Archimedes construct his great concave mirrors. This of course was through a desire to drive away the besieging Romans and set afire their ship rather than through a disinterested passion for discovering the laws of optics.

I suppose, however, it is not much different today, when government support for science, and scientific research in most cases—particularly if we are talking about large-scale support—is geared towards defence, towards solving anticipated energy or material shortages, or other pragmatic aims. Such was the case in nuclear physics, in the moon expedition, in missiles development and the like.

There is one recorded example of government aid for pure research which I can recall. When Eratosthenes formed a project for determining the circumference of the earth, King Ptolemy III, an enlightened Greek despot sitting on the summit of the age-old bureaucratic pyramid of Egypt, placed the royal corps of surveyors at his disposal to measure the arc of longitude between Syene and Meroe. A hot, thirsty, dusty job it must have been, but then Egyptian governments seldom became neurotic over industrial relations.

In what we call the Middle Ages, government was even less a patron of science than in Graeco-Roman times, although the first beginnings of artillery, which stimulated interesting developments in mathematics, attracted some attention from government. Curiously enough, it was the Middle Ages which, by the application of the windmill, saw the first major step away from muscle-power in industrial processes. But in essence it is only the last few centuries which have seen the rise of a close interaction between governments and the physical sciences, as the latter have moved from the workshop through the laboratory to the Research Establishment.

Today we are not surprised, indeed we expect, that important and fundamental work in the

[1] Read at an evening meeting held at the University of Western Australia on 24 April 1978 as part of a symposium entitled "What is Science?" organised by the Royal Society and the University of Western Australia Extension Service.

physical sciences will be done in a government research station, or at all events in a university which depends upon the taxpayer's money.

Yet this fact might well have surprised our grandfathers, for government research stations are a very recent growth. Within living memory the older universities were private corporations independent of public funds. Deriving their wealth from the rents of lands (usually the benefactions of former centuries), and assisted by private donations of the wealthy, either for particular or for general purposes, they provided until a couple of generations ago a haven for men who wanted to advance learning, as well as for many who wanted only a quiet and comfortable life. The funds which they thus controlled were adequate for many kinds of study and research.

In the nineteenth century, however, the physical sciences and their practical applications made very great advances, and many of the growing-points of knowledge were outside the universities. For the latest progress in metallurgy, and the design of machines, the bustling workshops of Henry Maudslay, Clement, Nasmyth and Bramah were a better school than the dreaming spires of Oxford.

These engineers were sternly practical men. They were financed (when they needed it) by sternly practical men of business who could see the advantages flowing from the improvement of tool steels and bearing metals and from the application of superheating to steam engines; and of course the assisting of technological research for comparable reasons still finds its place in the profit and loss accounts of big manufacturing firms.

Pure research could not so easily find private backers, and so, among the educated public a sentiment grew that the universities must include scientific research among their activities. Thus at the University of Oxford, that same decade which saw the removal of religious qualifications for the master's degree saw the provision that the colleges must contribute a part of their revenues to the university, with a view especially to the encouragement of natural science. The old sources of revenue now ceased to be enough, and after the First World War, Oxford received—with many doubts and heart-searchings—its first government grant. The timing is interesting, for the end of that war marked an epoch in English government also.

In 1918 women first became able to vote, and consequently for the first time the electorate came near to being the entire nation. Two years later, the Nineteenth Amendment allowed American women also to become political animals. Thus those two great countries were only some twenty years behind Western Australia in this constitutional provision.

It is not an accident or mere fortuity that adult suffrage comes at the same time as governments busy themselves with science for only when a government claims to represent everybody does it meddle in everybody's business. Old-time governments, even when they called themselves democratic, like that of Athens in her prime, did not represent everybody. In all cases their franchise was restricted—in some by nobility of birth, in others by wealth, in others by status—but in all according to some notion of fitness to have a voice and an influence in affairs of state. This concept of fitness, which plays an important part in the doctrines of so libertarian a writer as Mill, plays no part at all in modern political thought or, if it raises its head, it is only to be instantly vilified.

Nowadays we are all equally fit or equally unfit, and we all vote for or against our government. You may think this an excellent thing; you may consider that precisely the same quantum of political sagacity resides in the illiterate teenager as in the emeritus professor; you may think that on questions of economic policy the undischarged bankrupt is as good a man to consult as the succesful director of a giant enterprise; or you may look back wistfully to the days of property qualifications and educational qualifications. But whatever your views, 'one man, one vote' is the system which we now have, and it is not likely to be changed in the foreseeable future.

It is in this system that the scientist and members of government pursue their different activities and purposes, and by this system that they are both conditioned.

The ends of the scientist are principally intellectual. He wants to arrive at new truths, usually by way of experiments under controlled conditions, proceeding by inductive reasoning from particular observations to general laws, which he then tests again by seeing whether their predictions are fulfilled in a new set of particular observations.

But if he is what we call a social scientist, that method of controlled experiment is not normally open to him, and he must rely on the statistical method instead, that is on the records of observations in the past of phenomena which cannot be repeated under the same or under optionally varied conditions.

Here he is on less sure ground because he must select the facts which go into the computer, and if his selection should have excluded any relevant or included any irrelevant fact, the utmost refinement of mathematics will not bring him to the right answer. Consequently there is no guarantee that his advice to government is right. But whatever method he uses the scientist is supposed to be objective, so far as our imperfect human nature will permit.

The tasks of a government go far beyond the administration of the existing code of laws; government must also be alert to detect faults that may develop in the laws, and to amend them if the interest of the people as a whole demands it. New technical developments commonly call for new laws; thus the factory system, the railway and the motor-car each brought forth necessarily a mass of legislation;

and for international air travel an ideal code of laws needs yet to be devised.

New laws necessitated by new technical developments have another nasty, but necessary characteristic—they cut further and further into individual liberties. Some of you might have enjoyed, as I did, the Dyason lecture given decades ago in Winthrop Hall by Professor Toynbee. If you did, you will remember how he exemplified this truth. "In my youth", said the Professor, "I would have called anyone a fool who would have told me that by coming on a red light I will be prevented to cross the Queen's highways. Such an intrusion in my personal rights and liberty would have been unimaginable. Yet today,", he went on sadly, "we all accept this restriction".

A politician as member of government has to take a decision that is going to be acted upon; he usually takes expert advice (if such a thing exists and is available), he must exercise his judgment on that advice, and then make his decision. Unhappily he cannot move with the majestic deliberation of a research worker who matures a theory over some twenty years or takes half a decade to classify a beetle. A member of government will use inductive reasoning as the scientist does, but urgency often forbids the careful checking by difference and similarities which scientific method prescribes. And when he has reached a tentative decision, he must reverse his method and apply deductive processes, examining in his mind the consequences in individual cases of the universal proposition which a law must necessarily be. In the light of any one or of more of these particular consequences, he may wish to modify the general law.

In all these operations of the mind there is an analogy between what scientists do and what governments do; for the scientific method is only organised commonsense, and commonsense is a quality without which government will not go very far.

But in the limitations imposed upon them governments differ greatly from scientists. The scientist makes his way (in principle at least) on merit. To earn his degrees he must satisfy acknowledged experts that he has mastered his trade. To gain academic appointment and promotion he must again give proof of his merit to those who are able to judge. And when he is once appointed, he has security of tenure; being fired by the boss is a contingency against which few university scientists would trouble to take out insurance.

But the poor politician, I hope to make your hearts bleed for him, leads a very different life. He makes his way by finding favour first with his party, then with the electorate, with thousands of voters who may judge him by the most subjective standards; by the length of his nose or the size of his teeth, by the way he looks over his glasses, or—in my case perhaps—by the thickness of his foreign accent. If the contest is a really close one, he may be nosed out by the misfortune of having been allocated by lot the last place on the ballot paper. These electors, who are his academic selection committee, are an unpredictable lot, who are always liable to turn against the favourite and back the outsider. In consequence the modern political analyst often has two occasions of displaying his powers, the first when he brilliantly demonstrates to us the way that the election must go, and the second when he explains, with even more compelling expertise, why his forecast went wrong.

As for security of tenure, there is little enough of that for the government, who every three years must go once again before its capricious selection committee; and this uncertainty may well influence its long-term planning. It is conceivable that a government, taking aim seriously at what it knows ought to be achieved, may calculate that four or five years may be necessary for the required measures to be implemented and to have the beneficial effect, that is hoped. Hence a government, unless it had a quite remarkable confidence in the outcome of the next election, might very well shrink from introducing even the most salutary measures.

I sometimes wonder how much of scientific research would be stultified if every scientist were liable to be discharged from his job at the end of every triennium; if he were to submit himself every three years to a new selection, the selectors comprising the whole adult population. One could also wonder of course how would governments function if their members were selected on merit for a long term of tenure.

This short tenure of office also obliges government to spend a considerable part of its energies, (particularly towards the end of a term) to estimating, anticipating and to some measure managing public opinion. The words "public opinion" are easily spoken, but the thing itself is a nebulous and elusive entity. How do you find it out? How do you estimate the degree of popular support enjoyed by the pressure groups—the women's libbers, the homosexual law reformers, the road users, the friends of the earth? It is always possible that a well-organised pressure group may be regarded by the unorganised majority with indifference or contempt. As a government you have only one infallible way of finding out the state of public opinion, that is by seeing what happens to you at an election; but that is like being sandbagged in the dark. Can we somehow see the sandbag in advance?

The power of the mass media is a hotly-disputed topic. On the one hand, the effectiveness of television advertising has been proved again and again. One might well think that the same skilfully applied pressure, which makes us change our soap-powder could go far to making us change our government. On the other hand, to switch from one brand of soap

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powder to another is relatively cheap and not a dangerous experiment; but the decision that it's time for a change in one's government could be expensive, even perilous, and therefore consumer resistance might well be higher.

The effectiveness of the mass media (in other ways than advertisements) in influencing public opinion is a matter on which decisive proof is hard to obtain. It seems to me however that, in a country where press, radio and television are free, they have much more power in influencing public opinion, than government does. Indeed, I am quite satisfied from my own personal experience that the media do not reflect and express public opinion as they claim, but that they create, formulate and influence public opinion, Hence it is questionable today, I think at least, whether public opinion exists at all or is it media opinion, renamed public opinion? At all events, it is one advantage which the scientist enjoys over government, that he very seldom has to bother whether the newspapers or the ABC are against him.

This advantage is one aspect of the scientist's freedom from the permanent warfare of party politics. In most matters connected with his expertise he will agree with his colleagues. Even where he quarrels with them, the issues are normally thrashed out in publications which none but the specialist reads, so that the general public seldom beholds the spectacle of scientists at loggerheads. On the other hand, such headings as 'Court lashed over bauxite' or 'Grayden hits at critics' are in every issue of *The West Australian*. Indeed, the only times when scientists brawl in public are when they advise governments. Then, I fear, some of our deplorable pugnacity must rub off onto them; for scientific detachment seems to take a back seat when wood-chipping or uranium-mining comes into question. Further, such brawls seem always to drag in on the one side the fears of those who distrust and resent all change, and on the other the restless meddling of those who favour any change for change's sake.

Amid the tumult government must take the decision and bear the responsibility, knowing that it may reach that decision on the basis of the best advice at the time, but that it will be judged entirely by the event, whether predictable or not; indeed very often those who least expected something themselves will be the readiest to blame government for not foreseeing it. This tendering of advice by science to government is one aspect of their complex interaction, by which government funds science and science advises government what to do with its funds. If the moneys available were unlimited, problems of funding scientific and technical research would be a great deal easier; for all learning is good, and one would like to help all reasonable projects.

But funding scientific research is in some respects like planning a curriculum for a school, for in the latter case it is possible to make out an argument in favour of any given subject in itself. Who can say that there is no value at all in studying Sumerian mythology or the history of glass-blowing? Yet only a few subjects can find room in the timetable, and in consequence each has to show not only absolute merit, but relative merit in comparison with its rivals. Thus, if there was enough money, one would gladly pour ample funds into research programmes in solar energy, tidal energy, wind energy, wave energy, geo-thermal energy, to say nothing of the complex problems of nuclear energy and its by-products. But there is not enough money, and a government is always tempted to simplify matters by supporting a few claimants only and rejecting most others.

Similarly, based on economic reasoning, there is the catch-cry of not duplicating scientific research, or even educational institutions (some of you might be familiar with the celebrated Partridge report). "Bigger is cheaper" is the accepted slogan here. I always thought this was false economy. Not only is bigger not necessarily cheaper, but it does not achieve the best possible result since it only achieves one result leaving aside and dormant the many possibly better results through different, better approaches.

Such "no duplication" decisions are attractive to the bureaucratic-administrative mind, but they can be disastrous. Such a disaster befell botany and zoology in the U.S.S.R. when Stalin decreed that only Lysenko was right and proletarian, while the other geneticists were wrong and bourgeois. By such decisions one does indeed avoid duplication of effort and expense; but in science as in politics some competition is necessary, for otherwise there would be no diverse original thoughts, but only one man's directives for other men to implement.

One thing, however, in this interaction of science and government is quite certain; government is never likely to go wrong for lack of expert advice; indeed it is more likely to flounder in a sea of it. I have sometimes wondered whether administrators of earlier centuries, with little or no scientific advice, made worse or better decisions than we do. The population of this State first passed the million mark in 1971. I wonder how many of us would be here if the first settlers had to wait for the results of a feasibility study, whether Western Australia should or should not be settled?

Mr Chairman, I fear I have spoken too long, and presumed upon your good nature too far. Perhaps you did not take the necessary scientific advice, for you might not have invited me if you had appointed a committee of statisticians to estimate how long it takes a Minister to run out of fuel and energy once he opens his mouth. But if I have taxed your patience too greatly, I can only say with the celebrated entertainer Tom Lehrer, who is a scientist but not a politician—"You should never have let me begin".

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Vertebrate remains from a stratified Holocene deposit in Skull Cave, Western Australia, and a review of their significance

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Abstract

Skull Cave is a collapse doline which has acted as a pit trap to animals living in the vicinity of the cave. A small excavation was made in a richly fossiliferous sandy floor deposit and 22 species of mammals were recorded. Comparisons are made with other modern and fossil records from this region and it is suggested that a retraction northwards or local extinction of three taxa *(Bettongia lesueur, Petrogale* sp. and *Notomys* sp.*)* occurred during early Holocene time and of two taxa *(Perameles* sp. and *Pseudomys albocinereus)* at some time after 3 000 years B. P. but before historic time. Evidence for the invasion of this region by another species *(Rattus tunneyi)* about 3 000 years ago was found. All of these taxa are known to inhabit heath or scrubland but not forest. During the Holocene, there appears to be a considerable degree of stability in the composition of fauna which include forest in their habitat. Human remains and some artifacts were found, but it is questionable whether the cave was an occupation site. Two radiocarbon dates based on charcoal indicate that the deposit so far excavated spans most, if not all, of Holocene time.

Introduction

Skull Cave is situated in aeolian Tamala Limestone of the Cape Leeuwin-Cape Naturaliste region, at latitude 34° 17′ south and longitude 115° 06′ east (Fig. 1). It is registered with the Lands and Surveys Department as cave AU 8 (Bridge 1973).

The cave comprises a large main chamber with a partially collapsed roof forming the entrance, and a small extension leading off the western part of the chamber. A large rubble pile about 13 m in height from the present sandy cave floor has formed below the entrance. The cave walls are either overhanging or nearly vertical, and there is a further 10 m approximately from the top of the rubble pile to the entrance above, hence the cave now acts as a pit trap to many of the animals living in its surroundings. Both chambers have been partially filled with sandy sediments washed into the cave, and the excavation walls show thin interfingering bands of brown, orange and sometimes whitish coloured sediments. Much charcoal is present throughout the deposit.

Remnants of a breccia were noticed adhering to the cave wall about 2.5 m to 3 m down from the entrance. Examination of the samples (G13407) collected suggest that this sediment is part of a previous cave floor which has since collapsed into the main chamber below. No biotic remains were found in any of the breccia collected.

Skull Cave is located in one of the several patches of open forest in this area and is surrounded by high closed forest of *Eucalyptus diversicolor* to the east and north, open scrub (the principal component being *Agonis flexuosa*) merging into low open scrub to the west and low open woodland (*A. flexuosa)* to the south (Smith 1973). Further north and east is open forest principally of *E. marginata.*

The excavation and methods

During November 1969, a small excavation was begun in the southern part of the main chamber (see Fig. 2) and was completed in 1971. The trench, later recorded as Trench A, was 1 m wide and 1.5 m long and it was excavated to a depth of 190 cm where a thick crystalline flowstone was encountered. In March 1973, a second trench (Trench B) was begun adjacent to Trench A; its dimensions were 1 m wide and about 1 m long, and about 115 cm deep. At this depth the sediment was so firmly cemented by calcium carbonate that excavation even with hammer and chisels was ineffective. This trench was completed in 1975.

Because the different layers or bands in the deposit were usually less than 1 cm in thickness, excavation by natural stratigraphic layers was not feasible and was therefore done by arbitrary levels, following the general dip of the sediment. All depths were measured from the sandy floor surface.

Figure 1.—Location of fossil sites in the Cape Leeuwin-Cape Naturaliste region, Western Australia.

Material excavated from both trenches was shaken on a sieve of 3 mm square openings and all bone was retained. Stone material of artifactual or geological significance was also kept. All specimens are lodged at the Western Australian Museum.

Accumulation and nature of the bone sample

The structure of Skull Cave renders it an efficient pit trap to animals living in the area, and it is likely that much of the faunal sample accumulated in this way. In fact two animals, a Pigmy Possum *(Cercartetus concinnus)* found on the surface in "shallow excavation" (see Fig. 2) and a domestic cat found near the base of the rubble pile, fell into the cave during the period of my visits. Accumulation of bone in a similar manner has been previously described in Australia (e.g. Bain 1962, Lowry and Lowry 1967) and elsewhere (e.g. Martin *et al.* 1977).

Within the deposit excavated in Trenches A and B, bones were found often still articulated, and in several cases skull, dentaries and some post-cranial bones, all attributable to the same individual, were recovered. These associations of several bones of one animal indicate that little disturbance has occurred since the animal died or was deposited in that position. An excellent example of this was found in the lowest levels of Trench B where parts of the skeleton of an adult Grey Kangaroo *(Macropus fuliginosus)* were collected. The limb bones were still articulated but both tibiae were broken, presumably resulting from the animal's fall into the cave; the breaks were not fresh but thinly coated with calcium carbonate, and the two parts of each bone had not been displaced as might have been expected if they had been broken by a falling rock.

A small proportion of the bone sample may have been washed into the cave along with sediments from the surface outside or washed to the excavation site from the rubble pile. Mechanical abrasion and/or chemical weathering were noted on only two specimens (each a dentary fragment of *Pseudocheirus peregrinus* 76.10.291 and *Trichosurus vulpecula* 76.10.369) and it is possible that these specimens were derived from either the rubble pile or, more likely, outside the cave. Some specimens were possibly reworked from another locality within the cave; similar cases are discussed by Archer (1974) and Milham and Thompson (1976). While it is believed the bone sample from Trenches A and B was mostly *in situ*, evidence of possible reworking within the cave has been found; a calcaneum identified as *Zygomaturus* has been recovered from a depth of 265.5-365.5 cm in an excavation made by R. Howlett, (pers. comm.). *Zygomaturus* has been previously recorded from a Pleistocene deposit in Mammoth Cave and from Strongs Cave (Merrilees 1968) and a tentative identification of a single tooth as *Zygomaturus* has been made at Devil's Lair (Balme *et al.* 1978). All of these finds are from sites considerably older than the dated deposit excavated in Skull Cave. The breccia in Skull Cave may have been the original source of the *Zygomaturus* specimen, and its contemporaneity with the sediments from which it came is in some doubt.

Bones representing several taxa showed evidence of charring: *Antechinus flavipes* (76.10.55), *Isoodon obesulus* (76.1.99), *Perameles*

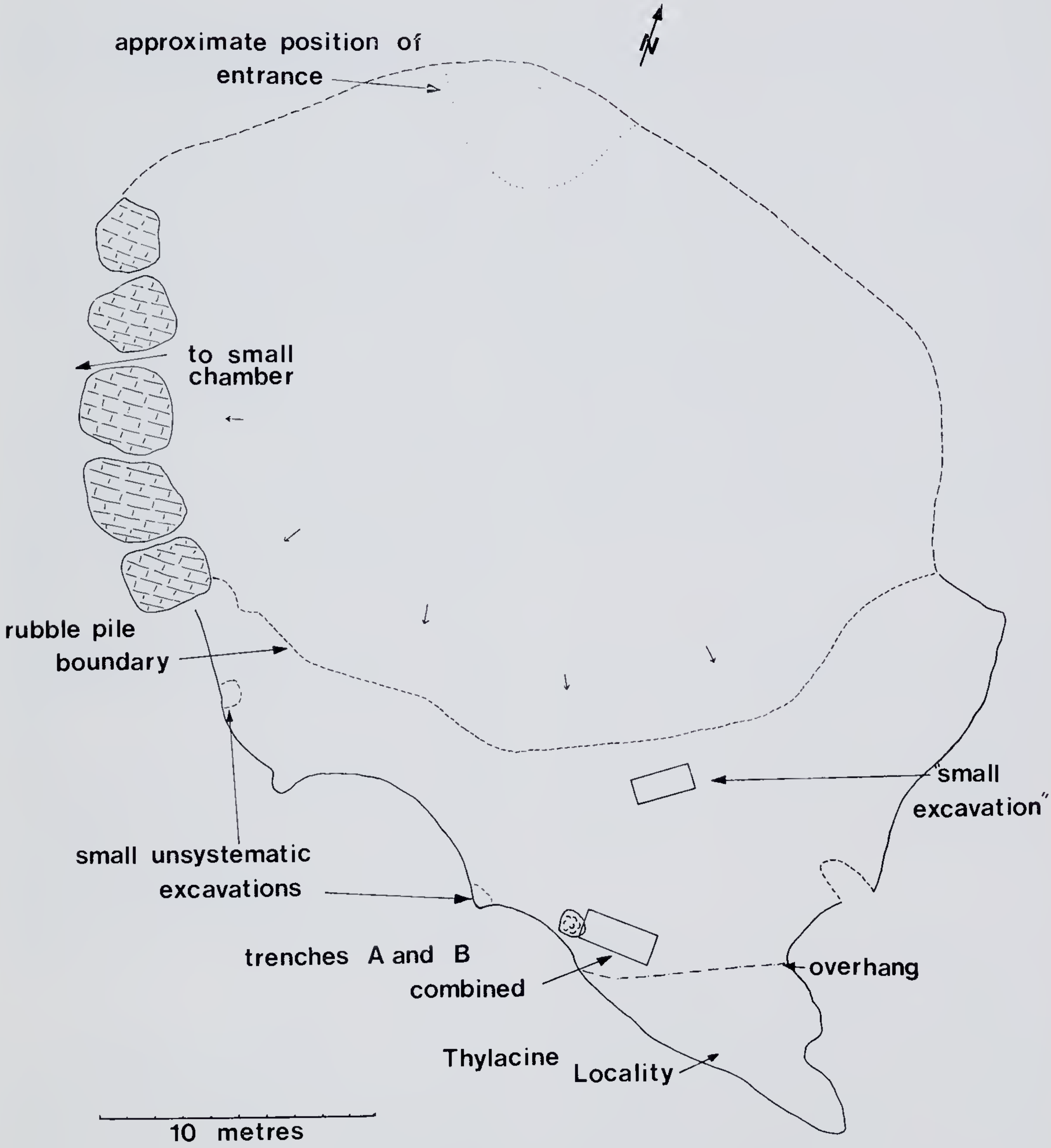

Figure 2.—Plane table survey of Skull Cave, Western Australia.

sp. (76.10.287), *Pseudocheirus peregrinus* (e.g. 76.10.244) *Potorous tridactylus* (76.1.119), *Setonix brachyurus* (e.g. 76.1.120) and *Rattus fuscipes* (e.g. 76.10.186). Charred bone occurring in caves could result from cooking or burning of animal carcases in hearths made by human occupants or could be the remains of animals charred during a bushfire and later washed into the cave. Several large charred tree trunks or limbs are present on the rubble pile in Skull Cave, and it is probable some charring of the many bones scattered over its surface occurred within the cave. While both artifacts and human remains (see below) have been recovered from various parts of the cave, they are few in number and no other evidence suggesting occupation of the cave has been found as yet. In its present state the cave would probably have been inaccessible to humans unless some structure was made to reach down from the

upper part of the cave wall to the top of the rubble pile. The possibility remains that the cave was used by humans but it is likely that such visits, if they occurred, were infrequent, and the few fragments of charred bone recovered were sparse and were probably charred by natural agencies.

Owls may have used the cave as a roost and the remains of smaller animals (especially murids and small dasyurids) from regurgitated pellets could have been incorporated into the deposit in this way. There is not a large preponderance of such smaller animals as is typical of owl-pellet deposits (Archer and Baynes 1972) and it is considered that owls were not major contributors to the faunal sample. However, even a small contribution may be of significance. Much of the bone sample resulted from animals falling into the cave by chance, and such a sample would be representative of at least part of the fauna living in the immediate cave surrounds. The presence of *Perameles*, *Pseudomys albocincreus*, *P. praeconis* and *P. shortridgei* (see below) which are known to inhabit heath and scrubland, but not forest may be due to owls which include both regions in their predatory range.

Age of the deposit

Two radiocarbon dates based on charcoal samples were obtained from an upper and intermediate level in the excavation. The upper level, 21-28 cm in Trench B, was dated as 2 900 ± 80 yr B. P. (SUA 227) and the intermediate level, 100-115 cm in Trench A, yielded a date of 7 875 ± 100 yrs B. P. (SUA 228).

A depth of 190 cm was reached in Trench A and assuming a constant rate of accumulation of sediments, this level can be roughly estimated as late Pleistocene or perhaps early Holocene.

The human components

The remains of more than one individual of *Homo sapiens* have been found in different parts of Skull Cave. A nearly complete mandible (A 22738) was discovered in the small western extension. It was found on a limestone boulder but was covered in brown dust typical of the cave sediment and was probably dug from the deposit nearby. No teeth are present in the mandible and the specimen was probably considered an uninteresting bone possibly from one of the several unsystematic "digs" in the cave. In Trench B, 28-34 cm, a human metatarsal (A 22915) was recovered, and a complete radius of an adult (A 22968) was found on the surface of the rubble pile.

A few artifacts of quartz, limestone and bone were excavated from Trenches A and B and are included in Table 1. Other small pieces of quartz, usually between 2 and 4 cm in diameter were also found, showing considerable rounding but no sharp fracture surfaces. These may have been the "cropstones" of birds. Tyne and Berger (1959) note that many seed-eating birds eat grit and Meinertzhagen (1954) mentions that quartz is often ingested. Six flaked quartz fragments may be remnants of flaking, presumably done on the forest floor outside the cave and subsequently washed in along with sediments. One quartz flake and two chips were also found.

A flaked bone splinter showing fracturing along one edge (presumably from use) was excavated from 115-127 cm in Trench A. The artifact was made from the limb bone of a large animal, probably a Grey Kangaroo, *Macropus fuliginosus*.

All archaeological specimens have been lodged in the Archaeology Department of the Western Australian Museum with the catalogue numbers B 2597, B 3517, B 3518, B 3523, B 5430-B 5439.

The fauna from trenches A and B

Trenches A and B were dug in arbitrary levels with depths measured from the cave floor surface; data from the two trenches were combined and are given in Table 1. Estimates of the minimum numbers of individuals were made using methods described by Baynes *et al.* (1976) and for names and species concepts I have followed Ride (1970). Catalogue numbers for the vertebrate fauna are 70.7.187-70.7.348, 71.10.115-196, 74.8.5-222, 76.10.1-438, 76.10.484-487.

Many land snails were recovered from the surface of the cave and within the excavated deposit, and these are lodged in the Palaeontology collection of the Western Australian Museum.

From about 115 cm to the bottom of each trench, sediments were cemented by calcium carbonate such that the whole of the bone sample from these levels was not easily retrievable, and numbers of individuals in these layers are notably fewer. Generally, numbers of individuals of most species recorded are too few to suggest trends or changes in relative abundance. However some emphasis can be placed on the presence or absence of certain species within the deposit as compared with other records for this region.

Comparison of the faunal assemblage with modern records

At the time of arrival of European man in Western Australia, the mammal fauna of the Cape Leeuwin-Cape Naturaliste region included *Dasyurus geoffroii*, *Phascogale tapoatafa*, *Sminthopsis murina*, *Trichosurus vulpecula*, *Pseudocheirus peregrinus*, *Cercartetus concinnus*, *Tarsipes spencerae*, *Bettongia penicillata*, *Macropus fuliginosus*, *Setonix brachyurus*, *Hydromys chrysogaster* and *Rattus fuscipes*, and it is probable that *Antechinus flavipes*, *Isoodon obesulus*, *Potorous tridactylus*, *Pseudomys praeconis*, *Pseudomys shortridgei*, *Rattus tunneyi* and *Canis familiaris* were also present (Baynes *et al.* 1976). *Sarcophilus harrisii* has not been recorded from this area during historic time. However, Archer and Baynes (1972) report a *Sarcophilus* tooth from a deposit dated

Table 1

Minimum numbers of individuals of mammals and other vertebrates excavated from Trenches A and B combined, and artifacts recovered.

Depth from surface	*Dasyurus geoffroii*	*Phascogale tapoatafa*	*Antechinus flavipes*	*Sminthopsis murina*	*Sarcophilus harrisii*	*Isoodon obesulus*	*Perameles* sp.	*Trichosurus vulpecula*	*Pseudocheirus peregrinus*	*Cercartetus concinnus*	*Tarsipes spencerae*	*Potorous tridactylus*	*Bettongia penicillata*	*Macropus fuliginosus*	*Setonix brachyurus*	*Hydromys chrysogaster*	*Pseudomys albocinereus*	*Pseudomys shortridgei*	*Pseudomys praeconis*	*Rattus fuscipes*	*Rattus tunneyi*	*Canis familiaris*	bats	birds	lizards	snakes	frogs	artifacts	C^{14} dates
cm																													
0– 7	....	1	3	3		5		3	3	2	....	2	1	1?	3	....	....	4	....	14	4	....	....	7	7	P	16	2 flaked quartz fragments 1 quartz chip	
7– 14	1	1	5	4	....	4	1	4	5	2	.	3		1	5	...	.	2	.	12	4	...	1	8	5	P	21	flaked calcrete fragment	
14– 21	2		3	.	....	3	...	4	5	2	....	4	2	1	6	....	....	3	....	6	4	1	..	4	5	P	30	? flaked bone fragment	
21– 28	1	1	6	1		2		4	4	1	.	3		1	5	1	1	2		9	1		.	11	5	P	21	3 ? limestone artifacts	2 900 ± 80 yr B.P.
28– 35	.	.	2			1	1	2	1	1	..	1	....	1	3	....	....	1	....	7	....	....	...	5	1	P	6		
35– 42	....	....	3	...	1	2	1	1	5	3		2		1	3	...	2			5	....	..	1	9	6	P	28		
42– 63		1	10	2	..	3	2	6	6	8	..	4	....	2	7	....	1	2	....	18	....	...	....	8	12	P	87		
63– 70	2	....	10	1	....	2	1?	2	3	3		3	....	1	3	1	1	1	.	12	....	....		4	8	P	58	1 flaked quartz fragment	
70– 80	2	2	11	5		3	1?	5	4	11	1	1	....	1	4	....	3	3	1	27	....	....	....	7	12	P	39	1 quartz flake	
80– 90	1	1	4	5	....	2	1	1	4	17	....	1	....		4	...	1	1	1	22	....	....	..	11	10	P	36		
90–100			4		....	1	1	2	6		.	..	....	..	3	....	....	1	....	5	....	....	....	6	3	P	16	flaked calcrete fragment	
100–115	1	1	7	2	....	2	1	2	4	11	....	1		2	3	....	...	1	2	11	....	....	.	4	4	P	6	quartz chip	7 875 ± 100 yr B.P.
115–127		.	5	2	....	....	....	2	2	2	...	2	....	....	1	....	....	1	1	10	....	....	....	5	1	P	6	flaked quartz fragment bone splinter	
127–137			4	5	..	.	1	1	2	5	..	....		...	1	....	3	.	...	18	....	....	....	8	1	P	4		
137–144	....	1?	1	....	...	....	....	2	1	3	....	....	..	1	1	..	3		...	3	....	....	...	2	3	P	1		
144–150			1	1?	....	....		1	1	2	...	...	....	1	1	....	...	2	....	4	....	....	....	2	1	P	1		
150–160	....	....	....	1	....	1	....	1	2	2	....	1	....	1	2	....	2	....	....	2	....	....	.	1	2	P	2	flaked quartz fragment	
160–170	....	....		1	...	....	..	1	1	1	.	..	.	....	1	....	...	....	....	1	....	....	....	..	..	P	....	flaked quartz fragment	
170–180	....	....	....	....	....	....	....	1	1	1	....	1	....	....	....	....	....	....	....	1	....	....	...	1	.	P	....		
180–190	....	...	1	....	....	....	....	....	1	....	....	....	....	....	....	....	....	1	....	....	....	....	....	....	....	P	....		

P = present

430 ± 160 yr B. P. and in light of this date suggest the species may have been extant in this region at the time of European arrival.

All of these species occur in the Skull Cave deposit and a further two, *Perameles* sp. and *Pseudomys albocinereus*, were also recovered although they have not been recorded historically.

Comparison of the faunal assemblage with other fossil records

Only one fragment of *Sarcophilus harrisii* was recovered from Trenches A and B, but other specimens have been collected from within the cave. An interesting skull (71.10.209) with an aberrant tooth, which has been illustrated by Archer (1975), was collected by P. Kendrick in 1971 from the surface of a not easily accessible part of the cave floor where the cave wall is low. There is no reason to suspect that the specimen was not *in situ;* it is probably of quite recent age. Other records of *Sarcophilus* have also been made from several caves in this region (Lundelius 1960, Merrilees 1968, Baynes *et al.* 1976).

Pseudomys albocinereus has been recorded from various levels in Skull Cave, the youngest from a level 21-28 cm below surface which has been dated 2 900 ± 80 yr B. P. (SUA 227). Other sites from which this species has been found are Cave 3 at Turner Brook (Archer and Baynes 1972), Yallingup Cave from a deposit below two flowstones (Merrilees 1979), and at Devil's Lair (Baynes *et al.* 1976) (see Fig. 1).

Perameles has been recorded from Mammoth Cave in which it occurs more commonly than *Isoodon* (Merrilees 1968) and in Devil's Lair in which it is less abundant than *Isoodon* but not uncommon (Balme *et al.* 1978). Isolated specimens have also been found in Brides Cave, Cave Au 12 and Harleys Cave. Merrilees (1968) suggested that *Perameles* may have become extinct in this region in relatively recent time. The youngest specimen found in the Skull Cave deposit was at a depth of 7-14 cm below the surface. The specific identity of these various specimens has not yet been determined, but it has here been assumed they are conspecific.

The only record of *Tarsipes spencerae* frcm the Skull Cave excavations was from a level 75-80 cm depth in Trench A. Devil's Lair is the only other site in the Cape Leeuwin-Cape Naturaliste region where the species occurs as a fossil (Balme *et al.* 1978). Outside this region, the only other Western Australian fossil record is from Koala Cave near Yanchep (Archer 1972). The lack of records for this species is probably in part due to its fragility (Baynes *et al.* 1976), but it is also likely that cranial and mandibular remains, especially if broken, may easily pass unrecognised. Devil's Lair is the only site from which such specimens have been identified and these are mostly dentaries. In both Skull Cave and Koala Cave, and in most cases in Devil's Lair, identifications have been made on postcranial remains, commonly femur, humerus and pelvis.

Bettongia penicillata was present on the surface of Skull Cave and in the uppermost levels of Trenches A and B to a depth of 21 cm. There are several other records of this species for this region, both of considerable age (e.g. from Devil's Lair) and probably quite recent (e.g. from the surface of Harleys Cave). It is interesting to note that although *B. penicillata* was found on the surface in Harleys Cave, no specimens were recorded from the one metre of deposit excavated by R. Howlett. This absence from all but the uppermost levels in both of these caves may be a reflection of low population numbers during that time, or perhaps a contraction away from this area of the Cape Leeuwin-Cape Naturaliste region of the range of this species during the early part of the Holocene.

Pseudomys praeconis was only sparsely represented in the Skull Cave deposit. However, Baynes (in Baynes *ct al.* 1976) states that this is "typical cf the species in the southern part of its range". It was also recorded from Turner Brook (Archer and Baynes 1972).

A notable absence from the faunal list for the excavation is *Thylacinus cynocephalus*. Several specimens have been recorded from various parts of Skull Cave in excavations made by other collectors (e.g. Howlett 1960). It has also been recorded from other caves in the Cape Leeuwin-Cape Naturaliste region (e.g. Merrilees 1968).

A comparison of the Skull Cave faunal assemblage was made with that of Devil's Lair, a cave about 14 km ncrth of Skull Cave containing abundant mammal remains of late Pleistocene and early Holocene age ranging from about 35 000 yr to about 5 000 yr B. P. (Balme *et al.* 1978). It was found that five species (*B. lesueur, Pctrogale* sp., *M. eugenii, M. irma,* and *Notomys* sp.) were present in the upper levels in Devil's Lair, but absent from Skull Cave, and two species (*Canis familiaris* and *Rattus tunneyi*) were present in the upper levels of Skull Cave but absent from Devil's Lair.

B. lesueur, Petrogale, M. cugenii and *Notomys* have been recorded from Yallingup Cave from sediment beneath "dripstone" layers. *Petrogale* and *M. eugenii* have also been found in Deepdene Cave in a deposit of which the lower level has been dated 19 400 ± 1 200 yr B. P. (Kigoshi, Suzuki and Fukatsu 1973). The former also occurred in Strongs Cave (Merrilees 1968), Giants Cave, Museum Cave and The Labyrinth (Merrilees 1979). To date, there have been no other confirmed fossil records of *Petrogale, M. eugenii* or *Notomys* in the Cape Leeuwin-Cape Naturaliste region.

There are several fossil records of *Macropus irma* both of known antiquity (e.g. from Mammoth Cave, Merrilees 1968) and of unknown antiquity. However, Baynes (in Baynes *et al.* 1976) notes that all show signs of chemical alteration or encrustation indicating considerable age. *Macropus eugenii* has been recorded from Yallingup Cave but these may be of considerable antiquity; there appear to be no fossil records of *M. eugenii* attributable to an age younger than early Holocene. Both species

have been recorded from the Cape Leeuwin-Cape Naturaliste region during historic time (Baynes *et al.* 1976).

Canis familiaris and *Rattus tunneyi* were present in the upper levels of Skull Cave but absent from Devil's Lair. Only a single canine of *Canis* was recovered from the excavations in Skull Cave, this being from a level 14-21 cm depth below the surface. Other specimens have been recorded from the surface of this cave and many others in this region.

Rattus tunneyi has been recorded only from the surface and the uppermost levels in Skull Cave; the oldest is from a level 21-28 cm below surface and which has been radiocarbon dated as 2 900 ± 80 yr B.P. (SUA 227). It has been recorded from the surface of deposits in Yallingup Cave, Brides Cave and Mammoth Cave and all of these specimens appear quite recent. *R. tunneyi* was also listed as occurring abundantly in a deposit in Cave 1 at Turner Brook by Archer and Baynes (1972) and they postulated a late invasion into the Cape Leeuwin-Cape Naturaliste region by this species. In view of the occurrences listed above, it is suggested the species arrived in the area of Skull Cave about 3 000 years ago, and presumably a little earlier in the northern part of this region. Baynes *et al.* (1976) add that this late arrival to the region may be due to it being able to "maintain large populations in pockets of vegetation among mobile sand dunes at beach edges". As suggested by Baynes, Merrilees and Porter for the other "non-forest" mammals in Devil's Lair, the route for the invasion of this region by *R. tunneyi* was probably via the coastal heath and scrubland to the west of the forest.

Discussion and conclusions

Although the faunal sample recovered from Trenches A and B was not large, some inferences about the history of some species during the Holocene can be made with supporting evidence from other localities in the Cape Leeuwin-Cape Naturaliste region. Balme *et al.* (1978) suggest that *Perameles*, *B. lesueur*, *Petrogale*, *P. albocinereus* and *Notomys*, all of which were absent from the region in historic time, became extinct locally at some time during the Holocene.

Notomys, and similarly *Perameles*, *P. albocinereus*, *P. praeconis* and *P. shortridgei*, are species not known to include forest in their habitat range (Baynes *et al.* 1976) and one would expect owls, and perhaps other predatory birds, to have collected all of these species if they were present in the heath and scrubland to the west of the forest. However, only the latter four are present in Skull Cave and the lack of *Notomys* probably reflects an absence of this species from the area during the Holocene. It is possible that the absence of *B. lesueur*, also a non-forest mammal, from the deposit may be due to its absence from the area since owls would probably take juveniles of an animal of this size, if not adults (cf. Smith 1977). Owls could also prey on young *Petrogale*, but its absence may be due to other factors.

The presence of species typical of forested areas (e.g. *Setonix brachyurus* and *Potorous tridactylus*) in nearly all levels of the deposit in Trenches A and B suggests the close proximity of forest to the cave during the whole period of deposition. Heinsohn (1968) noted that potoroos in Tasmania apparently did not leave the dense vegetation even to feed on the adjacent lush pasture. The presence of nearly complete skeletons of adult potoroos in Skull Cave could only represent the victims of the pit trap, and this would suggest that the cave was surrounded by forest and not by open vegetation during much of the Holocene. Most other species in the faunal sample include forest in their known habitats, and the species which are indicative of vegetation other than forest could have been brought into the cave by owls. Therefore, the absence of *Petrogale*, and possibly of *B. lesueur* also, may not necessarily reflect an absence from this region but merely indicate that these species did not venture into the forest surrounding the cave.

Balme *et al.* (1978) note a decline in the relative abundance of *B. lesueur*, *Petrogale* and *Notomys* from late Pleistocene to early Holocene time. It is possible that the range of these species did not extend as far south as Skull Cave or that *B. lesueur* and *Petrogale* did not enter the forest and their absence from Skull Cave may not represent their absence from this area. However, there is a lack of Holocene fossils of these species from other caves in the region which suggests a retraction northwards of their range before the Holocene.

Macropus irma and *Macropus eugenii*, two species which include forest in their habitat range, have not been found in Skull Cave. Balme *et al.* (1978) suggest that dwindling populations in late Pleistocene times may have retracted northwards during the Holocene. Baynes (in Baynes *et al.* 1976), postulates a re-invasion of the Devil's Lair district by *M. irma* after the first felling of the forests last century. He also lists the closest modern occurrence of *M. eugenii* to Devil's Lair as 30 km north at Ellenbrook. The absence of these species from Skull Cave, and the paucity of other records for most of the Holocene support the view of a retreat northwards of *M. eugenii* and *M. irma*, from at least the southern part of their late Pleistocene distribution, during the Holocene.

A forest mammal which has become extinct in this region, and probably elsewhere, during the Holocene is *Thylacinus cynocephalus*, although it has not been possible to date this extinction in the Cape Leeuwin-Cape Naturaliste region. Many specimens have been recovered from unsystematic excavations in Skull Cave, e.g. one recorded from a "shallow excavation" (69.9.11) and another (70.4.285) from approximately 0.6 m below the surface in the walls of an abandoned excavation in the "Thylacine Locality" (see Fig. 1). By reference to the dated sediments in Trenches A and B, it is suggested that *Thylacinus* survived in the area of Skull Cave well into the Holocene. It has

been suggested that the extinction of this species may be related to competition for similar food resources with the Dingo, which may have arrived in Australia early in the Holocene (Archer 1974).

Bowler (1976), Kendrick (1977) and Rognon and Williams (1977) have presented evidence for dry periods at various localities between about 7 000 and about 3 000 years ago. However, there appears to be no indication of changes in the faunal composition attributable to such climatic variation, although a larger sample would be necessary to confirm this. Present sea level was attained by about 6 000 years ago (Thom and Chappell 1975) and the extent of the heath and scrubland to the west of the forest presumably was relatively constant by this time.

During the Holocene, the forest mammal component of the fauna of the Cape Leeuwin-Cape Naturaliste region (with the exception of *Thylacinus cynocephalus* and possibly *B. penicillata*) appears to have remained consistent. However, of the heath- and scrub-dwelling species, *B. lesueur, Petrogale* and *Notomys* probably disappeared from this region during early Holocene time, and *Perameles and P. albocinereus* at some time after 3 000 years but before historic time. These local extinctions represent the culmination of trends begun in late Pleistocene times perhaps initially influenced by marine transgression, but it is suggested that climatic or human effects were the determinants during terminal Pleistocene and early Holocene times (Balme *et al.* 1978). It is possible that dwindling populations of *Perameles* and *Pseudomys albocinereus* became so depleted by about 3 000 years ago that they were no longer viable, despite a possible change in climate which may have been favourable to them.

Although there was a depletion of the fauna during the Holocene, two species entered the region at separate times. *Rattus tunneyi* invaded the coastal region and made its first appearance in the vicinity of Skull Cave about 3 000 years ago and may have persisted in the region until the arrival of European man (Baynes *et al.* 1976). *Canis familiaris* may have arrived in the region earlier in the Holocene, but at a time not yet known.

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Morphology of small australites from the Eastern Goldfields, Western Australia

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Abstract

Forty-two australites (Australian tektites) of average mass about 1/4 g and of forms peculiar to small australites have been examined. Fractionally lower but more variable specific gravities compared with australites in the general size range are attributed to differential vapourization of constituents from these highly thinned forms by aerodynamic heating. Folding of hot glass during flight modified the shapes of some specimens. The morphological series comprising flanged forms, "small" flanged forms and discs or plates has been reviewed and is not seen to be parental to the most abundant type of bowls. An independent bowl series is proposed. There is a need for further studies of small australites if their types are to be more closely defined and their development understood.

Introduction

The general principles of australite morphogenesis are believed to be clear except in the cases of two groups of specimens. One group comprises small forms, generally of mass less than 1/2 g which have no shape counterparts amongst larger specimens; the other group comprises a variety of unusual or rare, so-called "aberrant" forms. This paper is concerned with the first of those two poorly understood groups.

The primary shapes of australites are believed to have originated when small bodies of melt were shaped by surface tension or by an equilibrium between surface tension and the centrifugal force arising from their rotation. The shapes of the cooled and consolidated primary bodies were modified by aerodynamic (secondary) processes during oriented, hypersonic velocity encounter with the earth's atmosphere and by minor breakage upon impact with the ground. The shapes have since been further modified by the terrestrial (tertiary) processes of weathering and erosion.

The shaping effects of aerodynamic processes were size-dependent. Specifically in the case of primary bodies of millimetre dimensions, the formation of flanges was even more important than it was for bodies of medium (1-3 cm) size. However, loss of the aerothermal stress shell beneath the ablation-stripped frontal surface such as occurred spontaneously from large bodies late in flight, or has often been completed as a result of terrestrial temperature changes for those of medium size, did not apply to small secondary bodies which had been aerodynamically heated throughout. The folding of hot, thinned (<3 mm), secondary bodies was a shaping process of some importance only in this small-size category.

The smallest primary bodies were probably entirely destroyed by aerodynamic ablation stripping. Others were reduced to sizes difficult to observe in the field. The small forms which survived the hazards of atmospheric braking have since been subjected to terrestrial destructive processes of various degrees of intensity. Chemical etching to depths of a millimetre or so by the constituents of soil water, which can develop minor sculpture on the surfaces of larger australites, is capable of disintegrating small ones. Abrasion by blown sand or during transport by running water such that a larger specimen is regarded as poorly preserved can modify a small one to the extent that little of morphological interest can be learnt from it. Terrestrial destructive processes have been disproportionately severe on small australites.

The most assiduous collectors of australites at the present time are the Aborigines and those who trade their finds to lapidaries are aware that very small specimens are useless for lapidary purposes. It is known that at least some Aborigines ignore small specimens, small natural fragments and flakes as being unsaleable. Several of the meagre total of 42 specimens which could be assembled for discussion in this paper were the discard from a collection made for sale.

Considering the profound re-shaping during atmospheric transit, the severity of terrestrial destructive processes and the difficulty of observation or intentional disregard of small

specimens in the field, it is understandable that so few well-preserved small australites are present in collections and that their morphogenesis is poorly understood. The criticism has been made that much attention has been given to large australites and very little to those at the other end of the scale. The answer to that criticism is that the only known, well-preserved, very small australites deserving of detailed study are those from relatively temperate and humid Victorian localities (Baker 1940, 1963, 1964; Baker and Cappadonna 1972; Birch and Cappadonna 1977; Cleverly 1977). The only recorded Western Australian small australites of the types concerned here are a bowl from the Kalgoorlie region (Baker 1940) and a variety of forms, mostly from Menangina Station (Cleverly 1973), but even the best of specimens from the semi-arid windswept interior warrant no more than brief notes appropriate to their weathered condition. Fenner (1934) has been cited as having recorded the presence of numerous small specimens in the W. H. C. Shaw collection (South Australian Museum) from Israelite Bay and part of the Nullarbor Plain, but all are of shapes represented amongst larger specimens. Bowls and other forms peculiar to small australites were not recorded by Fenner in the Shaw collection.

Material

Some physical details of the 42 specimens examined are shown in Table 1.

The definitions of "broad oval", "narrow oval" and "boat" shapes used in the table are those of Fenner (1940). The procedure adopted for specimens having a core is to classify the specimen according to the shape of the core, and if the shape of the flange differs, to add a rider to that effect. When a core is lacking, the specimen is necessarily named according to the overall shape. When a core is reduced to very small size it is probably no longer a reliable guide to the shape of the primary body but the flange is even less so. At the extreme developmental stages reached by these small australites, flanges tend towards round shape as seen in Fig. 6C where the narrow oval core has a broad oval flange; for further examples see Fig. 6V, W.

Specific gravities were determined by loss of weight in toluene of known temperature using a chemical balance except in the case of specimen No. 12 for which a Berman Balance was used.

The dimensions are stated in conventional manner with length and width measured in directions normal to the line of flight and the thickness parallel to the line of flight. All dimensions are between tangents to the curved shapes. The dimensions of the core, a central remnant of the primary body, are stated in the same way, or in the absence of a core, the thickness of the glass at the anterior pole is given. The overall thickness minus that of either the core or the glass is the depth of the posterior cavity. The average value of (flange width)/(core radius) can be calculated from the dimensions as explained in a subsequent section.

The specimens are the gleanings from more than 26 000 Eastern Goldfields australites dispersed in 20 collections, the majority of which contained no usable specimens. Specifically, the specimens are from the following collections which are indicated in Table 1 by the abbreviations given here; South Australian Museum (SAM); Geology Department, University of Melbourne (UM); Geology Department, W.A. School of Mines (WASM); the private collections of K. Jenkins (KJ), J. L. C. Jones (JLCJ), P. J. Simmonds (PJS); the Tillotson collection (TC) owned jointly by Mr and Mrs R. G. Tillotson and Mr D. J. Tillotson. Australites used for comparative purposes include specimens from the British Museum (Natural History) (BM) and the collection of the late Dr George Baker, now in the National Museum of Victoria (NMV).

Inclusive cf specimens previously described (Cleverly 1973 Nos. 1-20) and 60 which were rejected as being too broken or weathered to be informative, the small specimens constitute less than 0.5% of the Eastern Goldfields australites available for inspection. For reasons of observation and collection, the sample is insufficiently representative of the true proportion of these small forms and is most unlikely to contain the full variety of shape types.

Small australites occur at only a few of the numerous Eastern Goldfields localities from which australites have been recorded; those mentioned in Table 1 are shown in Figure 1. The locality "Kalgoorlie and district" warrants comment. That, or a similar locality attribution is found in the registers of at least five official collections for australites obtained from several early private collectors or from their estates. Some individual australites in those collections are known to have been found far distant from Kalgoorlie. In my opinion, "Kalgoorlie and district" reflects only the known fact that all of the private collectors concerned were residents of Kalgoorlie, though it is probable that the specimens were found somewhere in the Eastern Goldfields which were being actively prospected when the collections were made.

Unless otherwise stated, illustrations show the australite in flight orientation with the line of flight vertically downward. The plan view therefore shows the posterior surface of flight. In elevational views and vertical sections, "downward" means towards the bottom of the page.

Specific gravity

Specimen No. 8 has the anomalously low specific gravity 2.355 which is visibly attributable to bubble cavities. It has therefore been omitted from further consideration in this section.

Table 1

Shapes, physical details and sites of finds of small australites from Eastern Goldfields, Western Australia

No.	Collection	Shape	Mass (g)	S.G.	Overall dimensions (mm)	Core dimensions (mm)	*Thickness (mm)	Locality
1	SAM T451	"Small" button or cored disc, gently folded	0·172 1	2·437	8·1 x 6·6 x 3·6	2·9 x 2·2 x 2·0	....	Kalgoorlie or district
2	TC	"Small" button, gently folded	0·136 2	2·390	8·3 x 7·8 x 2·0	c4 x c3·5 x 1·6	....	Vicinity of Seven Mile Hill
3	KJ	Round bowl, "core" defined only by texture	0·108 7	2·441	(7·2–7·0) x 2·6		1·5	c 20 km W.S.W. of Mt. Remarkable H.S.
4	SAM T451	Round bowl, incipient folding	0·077 6	2·414	(6·2–6·0) x 2·1		1·5	Kalgoorlie or district
5	SAM T451	Round shallow bowl, slightly folded	0·121 3	2·402	7·1 x 6·5 x 2·4		1·8	Kalgoorlie or district
6	TC	Cored round bowl, about half folded	0·317 5	2·427	9·9 x 6·2 x 6·2	Not determinable		Vicinity of Seven Mile Hill
7	PJS 75	Cored round or slighly oval bowl, about half folded	0·356 3	2·431	9·9 x 7·1 x 5·7	Not determinable		c 10 km E. of S. from Widgiemooltha
8	JLCJ	Round or slightly oval bowl, about half folded, asymmetrically, core defined only by texture	0·197 7	2·355	8·7 x 7·1 x 4·1	Not determinable		Eastern Lake Yindarlgooda
9	KJ	Shallow round bowl, posterior surface almost flat	0·352 1	2·438	(10·0–9·6) x 3·4		2·7	c 20 km W.S.W. of Mt. Remarkable H.S,
10	KJ	Shallow round bowl, slightly folded	0·449 8	2·437	9·9 x 9·2 x 5·2		3·5	c 20 km W.S.W. of Mt. Remarkable H.S,
11	TC	Shallow round bowl	0·246 8	2·386	(9·1–8·5) x 3·5		2·8	Vicinity of Seven Mile Hill
12	SAM T561	Shallow, flat-cored, round bowl	0·058 4	2·440	(6·8–6·2) x 1·8	(4·3) x 1·4		Kalgoorlie or district
13	JLCJ	Shallow round bowl	0·419 4	2·439	(10·0–9·6) x 4·1		3·8	Central or north Lake Yindarlgooda
14	WASM 10 873	Cored broad oval bowl	0·235 2	2·437	9·3 x 8·0 x 3·4	5·6 x 5·0 x 2·6		Kalgoorlie district
15	TC	Broad oval shallow bowl, cored	0·240 4	2·427	9·2 x 8·9 x 2·8	4·2 x 5·0 x 2·4	1·9	Magnesite Ck., c 4 km E. of Bulong
16	JLCJ	Broad oval bowl	0·529 6	2·456	11·6 x 9·4 x 4·2		3·0	Eastern Lake Yindarlgooda
17	JLCJ	Broad oval bowl (fractured)	0·251 1	2·462	9·0 x 7·2 x 4·0		2·5	Central or north Lake Yindarlgooda
18	WASM 11 774	Broad oval shallow bowl, slightly convex core, boundary undefined	0·363 2	2·420	10·1 x 9·6 x 3·3		3·2	c 20 km W.S.W. of Mt. Remarkable H.S.
19	TC	Broad oval shallow bowl, core poorly defined	0·374 6	2·409	11·0 x 9·9 x 3·5	6·9 x 5·3 x 3·0		Taurus, N.E. of Bulong
20	KJ	Broad oval shallow bowl	0·296 2	2·465	10·4 x 9·4 x 2·7		2·2	c 20 km W.S.W. of Mt. Remarkable H.S.
21	WASM 11 775	Broad oval shallow bowl, very gently folded	0·239 1	2·435	9·2 x 7·9 x 3·6		2·5	c 15 km S.S.E. of Mt. Remarkable H.S.
22	TC	Broad oval plano-convex form	0·108 1	2·399	7·4 x 7·0 x 1·7		1·5	Vicinity of Seven Mile Hill
23	TC	Broad oval plano-convex form	0·060 2	2·403	7·0 x 5·4 x 1·3		1·1	Vicinity of Seven Mile Hill
24	KJ	"Small" flanged narrow oval with broad oval flange	0·188 3	2·465	8·8 x 8·3 x 2·3	5·0 x 3·3 x 1·8		c 20 km W.S.W. of Mt. Remarkable H.S.
25	KJ	Narrow oval bowl	0·145 6	2·435	9·0 x 6·0 x 3·0		1·5	c 20 km W.S.W. of Mt. Remarkable H.S.
26	SAM T561	Narrow oval bowl, slightly asymmetrical	0·159 8	2·446	9·1 x 6·4 x 3·0		1·6	Kalgoorlie or district
27	TC	Narrow oval bowl	0·263 0	2·457	10·7 x 6·6 x 3·5		1·8	c 6 km N. of Kanowna
28	KJ	Narrow oval bowl, slightly asymmetrical and slightly folded on transverse axis	0·148 1	2·440	8·0 x 5·0 x 3·9		3·4	c 20 km W.S.W. of Mt. Remarkable H.S.
29	SAM T451	Narrow oval bowl	0·080 8	2·385	6·6 x 4·3 x 2·4		1·6	Kalgoorlie or district
30	KJ	Narrow oval "tray" with thickened rim	0·376 9	2·450	16·6 x 9·2 x 2·7		1·6	c 20 km W.S.W. of Mt. Remarkable H.S.
31	SAM T561	Narrow oval "tray" with thickened tim	0·147 6	2·425	12·7 x 8·9 x 1·4		0·6	Kalgoorlie or district
32	JLCJ	Cored narrow oval bowl with broad oval flange	0·182 8	2·419	8·7 x 7·7 x 2·9	4·0 x 2·7 x 2·1		Eastern Lake Yindarlgooda
33	KJ	Boat-shaped bowl	0·098 4	2·429	9·8 x 4·2 x 3·0		1·2	c 20 km W.S.W. of Mt. Remarkable H.S.
34	TC	Boat-shaped bowl, slightly folded transversely	0·141 9	2·444	8·9 x 4·6 x 4·2	c 3 x c1 x 2·0		Vicinity of Seven Mile Hill
35	TC	Boat-shaped, "massive" type	0·423 0	2·436	> 13·8 x 6·7 x > 5·8		3·2	Vicinity of Seven Mile Hill
36	WASM 12 004	"Small" flanged teardrop with broad oval flange	0·128 3	2·417	8·2 x 7·6 x 2·1	5·1 x 4·3 x 2·0		10 km E. of Menangina H.S.
37	SAM T451	"Small" flanged teardrop with oval flange (fractured)	0·219 9	2·432	> 12·0 x > 7·9 x 2·5	c 9·3 x 3·8 x 2·4		Kalgoorlie or district
38	KJ	Shallow teardrop bowl with thickened rim and overfolded tail	0·131 1	2·394	9·0 x 6·9 x 2·6		1·7	c 20 km W.S.W. of Mt. Remarkable H.S.
39	KJ	Shallow teardrop bowl with thickened rim, part of overfolded tail	0·236 2	2·444	> 10·6 x 9·1 x 2·2		2·0	c 20 km W.S.W. of Mt. Remarkable H.S
40	TC	Shallow teardrop bowl	0·135 5	2·397	11·8 x 6·0 x 2·5		1·5	Vicinity of Seven Mile Hill
41	PJS 177	Shallow teardrop bowl with partial frontal collapse	0·348 6	2·446	12·8 x 9·5 x 2·6		1·5	Boomerang Lakes, c 10 km S.W. of Menangina H.S.
42	UM	Aberrant with teardrop flange	0·224 1	2·429	10·4 x 9·1 x 2·6		1·5	Kalgoorlie district

* Glass thickness at the anterior pole.

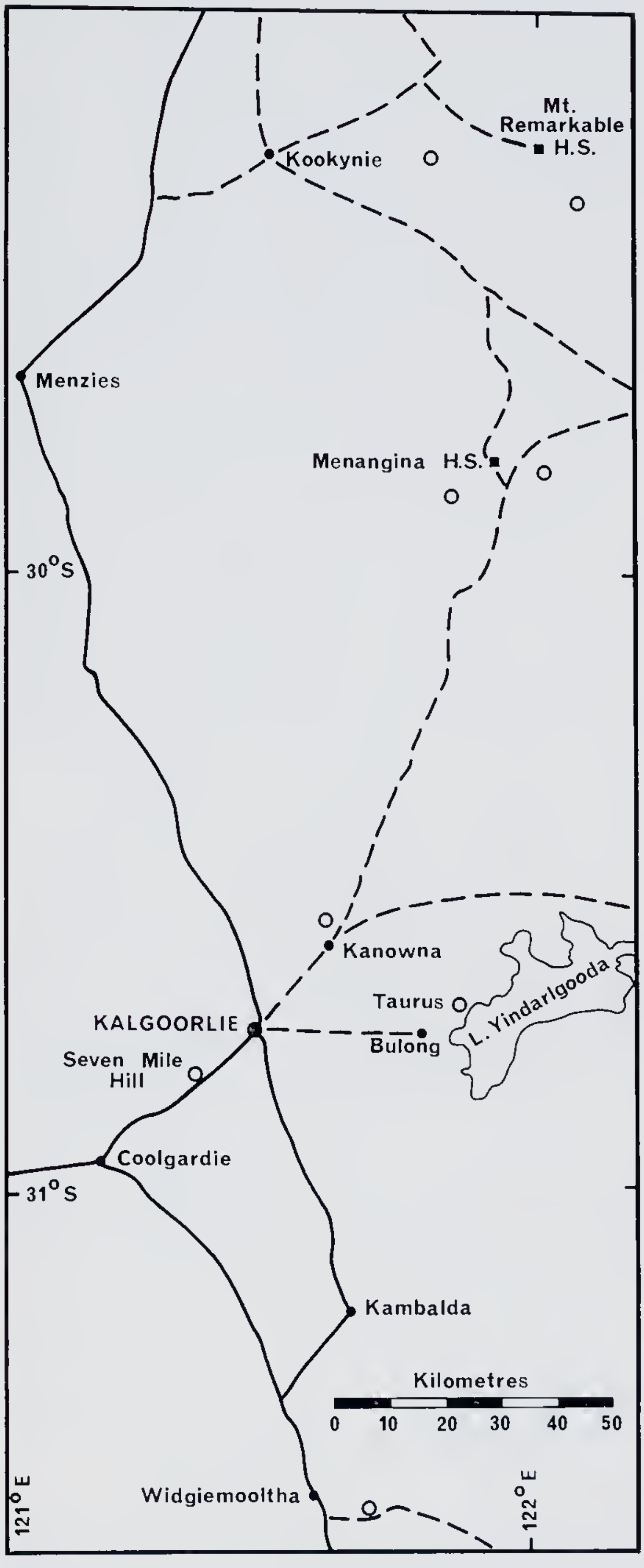

Figure 1.—Part of the Eastern Goldfields of Western Australia showing sites of finds of small australites (open circles) in relationship to major roads. Unsealed roads shown by broken lines.

The relative frequency polygon of specific gravity for a sample of 420 australites from the Kalgoorlie Area given by Chapman *et al.* (1964)

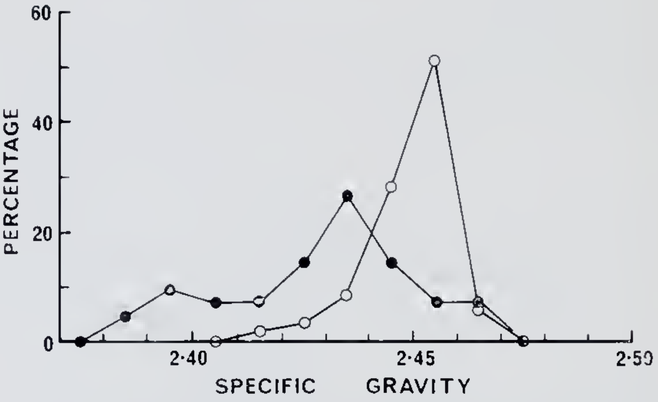

Figure 2.—Relative frequency polygons of specific gravity for australites. Open circles: polygon for 420 australites from the Kalgoorlie Area (Chapman *et al.* 1964). Solid circles: polygon for 41 small Australites from the Eastern Goldfields (this paper).

is reproduced in Figure 2. It shows a very clearly defined mode in the 2.45-2.46 interval. The polygon for the 41 small specimens is somewhat irregular, the mode is in the lower interval 2.43-2.44 and less defined, the whole polygon being flatter and extending down to lower values of specific gravity. The irregularity was to be expected because of the small numerical size of the sample, and the other features are understandable because secondary ("flange") glass has slightly lower specific gravity than core or body glass (Baker and Forster 1943). The lower value may be attributed to differential vapourization of constituents such as potassium with consequent residual enrichment in some lighter but less volatile constituents such as magnesium and aluminium (Lovering 1960). The proportion of secondary glass in these small specimens is evidently sufficient for its lower specific gravity to affect the value for the specimen as a whole. Such an effect is insignificant in larger specimens, even when they retain a substantial part of the flange. The proportion of secondary glass present is also very variable. Some specimens consist almost entirely of secondary glass and have therefore been strongly heated throughout. Hence the lower but more variable specific gravity values when compared with specimens representative of the general size range.

Role of folding in australite morphogenesis

During the later part of the aerodynamic shaping process when deceleration caused by air resistance approached a maximum, the shapes of small secondary bodies were sometimes modified by the folding of hot thinned glass. It will simplify the subsequent discussion if those morphological features which can be attributed with confidence to folding are first summarized. Three general types of failure by folding have been observed.

1. Frontal collapse of thin plates and bowls is seen as a dimple, not necessarily centrally located, or as a more extensive shallow concavity when a flow ridge or thickened rim provided a slightly stronger frame to limit the area of collapse. Partial frontal collapse is shown by a

number of the specimens under examination. Better examples are shown in Figure 5A-C, E. A dimple in the thinned frontal glass over a bubble cavity is not unusual (Fig. 5D) but is not confined to small australites. This feature may be present on any specimen which still has its anterior surface of flight i.e. has not lost the aerothermal stress shell or been too severely eroded. Failure of this kind is aided by the near vacuum conditions within the bubble cavity.

2. Backward folding of secondary structures is shown by the slender "tails" of teardrop specimens (Fig. 6N); more dubious examples from which the hinge may have been broken or eroded away are shown in Figure 6 O, P and very doubtfully in Fig. 6R. The frail "wings" (end-flange) of pine-seed forms (Skeats 1915) may be folded backward and moulded to the shape of the body (Fig. 5F). Some of these features were so frail that they would be readily broken on impact or by subsequent terrestrial erosion processes. In consequence, they are known principally in a folded condition and then only by those parts which are fused to the body of the australite. Because these australites were so thin they were heated throughout and folded parts making contact were fused together. Again, there is an exception amongst larger specimens. Very rarely, full-sized buttons show partial detachment of the flange which is smeared backward to result in a fold undulation in its posterior surface. Two views of such a specimen have been illustrated by Fenner (1934 pl. IV).

3. Backward folding on a hinge of the opposing parts of a complete form is shown by a variety of round and elongated specimens. Folding is usually only partial in thicker specimens (2-3 mm) but may be complete in the thinnest ones (1-2 mm). If the hinge is symmetrically located and the folding complete (like a butterfly with wings closed upward), the posterior surface of flight is no longer visible. The folding of round and slightly oval forms is usually on a diametral or approximately diametral hinge. The earliest stage is seen as a gentle regular undulation of the rear margin (Fig. 4 B(1), B(2), G(1) and others). When folding had advanced further, the sides are distinctly higher than the ends of the hinge (Fig. 4 H(2), Fig. 5K, L). No specimens in which folding was more than half completed are available from the Eastern Goldfields, but more completely folded specimens are available from other localities. Contact between the approaching sides was usually made first at the mid-points of the "lips" whilst the "ends of the mouth" allowed the escape of air enclosed between the sides. With essentially complete folding, only gas escape tubules remained (Fig. 4L(1)), or the sides are in contact except for a disconnected trail of trapped and flattened bubbles (Cleverly 1977 Fig. 1A). The hinge was not always symmetrically placed or at right angles to the length of elongated specimens. This has been illustrated by a broken elongated specimen with edge thickened by overflow (the "tray" type referred to in a later section), which has been folded on a longitudinal hinge about one third of the way across the width (Fig. 5G).

Folding is more difficult for a bowl than for a disc-like form where the hinge is within a plane and allows the two parts to fold over into complete contact. During folding of bowls or any trough-like feature such as the "wings" of pine-seed forms, the curved hinge tends to straighten, causing bulging at the ends (Fig. 5F). Complete contact between the sides is possible only if they are flattened, which necessitates further distortion of the form (Cleverly 1977).

Folding poses a minor problem in nomenclature because it is usual to name australites according to their shapes and proportions in plan view. Folding changes the proportions; length and width may even interchange locations if the hinge is transverse to the original length. Though an object should be named for what it is rather than for what it is thought to have been, it appears preferable in the present instance to make a few measurements and estimate the pre-folding proportions. It would be thoroughly misleading if the specimen shown in Fig. 4L(1) were described as a dumbbell instead of as a tightly folded round form.

Discussion

The development of small australites was envisaged by Baker (1958) as involving first the formation of "small" buttons which, with further growth of flange at the expense of core, became cored discs and thence discs. The thinnest discs then bent backward into bowl-shaped forms. The elongated equivalents behaved in analogous fashion.

The formation of buttons is well documented and experimentally demonstrable (Chapman and Larson 1963). Continued development into "small" buttons is likely because of the short time needed to reach the flange-forming stage i.e. the time when the ablation-stripped frontal surface encroached upon the "equator" of the primary body. The characteristics of "small" buttons (Baker 1958) are that the flanges are more flattened and constitute a greater proportion of the form than on buttons of ordinary size. It may be added that because of flange growth at the expense of core, the posterior pole of the core may be level with or fractionally below the posterior surface of the flange. The cores of six small buttons previously recorded (Cleverly 1973) are 0.2-0.6 mm below the flange. The further transition of "small" buttons into cored discs, the more exaggerated version of the same form and thence into discs are also understandable as the flange developed at the expense of core which became smaller and thinner (Fig. 4A to C).

The width of flange relative to core radius, which will be expressed here as F/C, could be used to make the distinction between "small" flanged forms and discs or their elongated equivalents (plates), if indeed such a distinction is justified. Some authors have tabulated flange width but there is a simpler arithmetical approach using the data of Table 1. The

required ratio is (overall diameter-core diameter)/(core diameter), or more simply, (overall diameter)/(core diameter) minus unity. For example, (overall diameter)/(core diameter) for six small buttons (Cleverly 1973 Table 1) is 1.74-1.99, and hence F/C is 0.74-0.99. For specimens having elongated core and/or flange, the averages of length and width may be used. Thus the "small" flanged oval and teardrop specimens shown in Fig. 6C and W have F/C 1.06 and 0.68 respectively.

Most of the disc, plate and bowl forms from Victoria described by Baker (1963) have F/C in the range 1-8 with mean value 2.9. The Victorian specimens described by Dunn (1916), as judged from rather small illustrations, show a similar range of F/C, except that in two specimens the core has almost disappeared. As the core dwindled to disappearance F/C would tend to infinity. The posterior profiles of the flanges are generally flat to concave, reflecting the high ratio of frontal area to mass and resultant severe deceleration (Chapman 1964).

Cored discs of the general style of those known from Victoria occur also in South Australia on Myrtle Springs Station where there have been unusually favourable conditions for their preservation (Corbett 1967 Fig. 5; Lovering *et al.* 1972 pl. 27). As estimated from the illustrations, they have F/C 1.2-2.7.

A comparison has been made in Table 2 between some of the disc and cored plate specimens described by Baker (1963) from Victoria and Western Australian material.

Pair 1. Though the specimens are of comparable mass and overall dimensions, the core of the "small" button is much the larger and this shows up in the F/C value. (See Fig. 6T and U.)

Pair 2. Mass, overall and core dimensions are reasonably comparable and the F/C values are the same. The only difference here is in opinions on nomenclature.

Pair 3. No Eastern Goldfields specimen of comparable mass was available, but the specimens are superficially much alike (Fig. 6V and W). In spite of the smaller mass and overall dimensions of the Western Australian specimen, its core is the larger in all three of its dimensions, which shows up in the F/C value.

Pair 4. Again, no specimen of comparable mass with the Victorian one was available. Other remarks apply as for Pair 3.

The impression may have been gained that the relatively fragile Victorian discs and plates would be distinguishable by small mass. In fact, the average mass of the 29 specimens recorded by Baker (1963) is 0.246 g and of the 42 Eastern Goldfields specimens examined is 0.226 gram. Two of the specimens described by Baker are heavier than any of those included here. After allowing 10% for the greater weathering and fracture losses from the Western Australian specimens, the average masses would not be significantly different. Lighter specimens are known from Victoria (Birch and Cappadonna 1977) but are not as appropriate for comparative purposes as those described by Baker.

From a comparison of the mean masses, it would be expected that the average dimensions of the Victorian specimens would be only fractionally larger, but their lateral dimensions average nearly 13% greater and plan view areas therefore about 27% greater, confirming their relative thinness and fragility.

I can see no natural divisions between buttons, "small" buttons and cored discs nor between their elongated equivalents. Most named specimens in literature would conform to the following values of F/C:—

Flanged forms	<0.7
"Small" flanged forms	0.7-1.0
Cored discs and plates	>1.0

These figures are not suggested as arbitrary definitions, but may be taken as a guide to past practice.

The problem of making a bowl out of a disc by the backward bending of flange as envisaged by Baker (1958) is somewhat akin to closing an umbrella without making use of the folds. The analogy is not as crude as might be supposed, because whilst the hot glass had the advantage of plasticity, it almost certainly had a major disadvantage in the shortness of the time available. The period of ablation flight of the

Table 2

Dimensions and masses of some small australites from Victoria and Western Australia

Pair No.	Registered number	Shape	Mass (g)	Overall dimensions (mm)	Core dimensions (mm)	*F/C	Reference
1	†NMV E7830	Cored disc	0·250	(9·8–9·6) x 2·6	(2·8–2·6) x 1·7	2·7	Baker 1963 No. 1
1	WASM 10 869	"Small" button	0·263	(9·5–9·2) x 3·0	(4·8) x 3·0	0·9	Cleverly 1973 No. 4
2	NMV E7836	Cored disc	0·127	(8·4–8·1) x 1·9	c 4·5 x c 4 x 1·4	0·94	Baker 1963 No. 7
2	WASM 10 609	"Small" button	0·146	(8·3–8·0) x 2·2	(4·2) x 2·0	0·94	Cleverly 1973 No. 6
3	NMV E7837	Teardrop plate with broad oval flange	0·309	10·6 x 9·9 x 2·8	4·5 x 3·2 x 1·7	1·7	Baker 1963 No. 9
3	WASM 12 004	"Small" flanged teardrop with broad oval flange	0·128	8·2 x 7·6 x 2·1	5·1 x 4·3 x 2·0	0·7	No. 36, this paper
4	NMV E7821	Frontally collapsed broad oval bowl	0·636	15·9 x 14·9 x 2·9	5·0 x 4·4 x 1·7	3·3	Baker 1963 No. 12
4	TC	Broad oval bowl	0·375	11·0 x 9·8 x 3·5	6·9 x 5·3 x 3·0	0·7	No. 19, this paper

* F/C signifies (Flange width)/(Core radius). † Victorian specimen is the first of each pair.

much larger, full-sized buttons from Victoria has been estimated as about 12 seconds (Baker 1967), though the bodies would have remained hot a little longer until velocity was checked to the level when heat input lagged behind heat losses. It is a rough rule of thumb that the australites would be stopped by encounter with their own mass of air (O'Keefe 1963); the time available for the development of small australites would therefore be significantly less than 12 seconds. Alternatively, one might think in terms of the aerodynamic drag equation in which deceleration is given by an expression having frontal surface in the numerator and mass (dependent upon volume) in the denominator i.e. having a linear measurement in the denominator. Other things being equal, a button 10 mm diameter would experience at any particular moment twice the rate of deceleration of one 20 mm diameter.

It seems likely that by the time a sphere was reduced to the flange-forming stage and passed progresssively through the button, "small" button, cored disc and disc stages, there can hardly have been more than a second or two during which it could be converted into a bowl. Yet crumpled bowl walls have not been reported, though bowls are the commonest of all small forms. Most of the observed folding was on a hinge. Folding of that kind must also be fitted into the available time unless it occurred after ablation-stripping ceased. This is a possibility because heating of the body of the form as distinct from a surface film may have been more effective when hot melt was not being stripped away almost as fast as it was formed, and for at least a short time, deceleration was still high.

Nor do bowls appear to have developed from "small" flanged forms. There are shallow bowl-like specimens which have the typical wide flange of the "small" form, but they are the result of folding on a hinge (see Fig. 4B(1), B(2)).

Another series of shallow bowls may be of more significance. These have low thick walls directed obliquely backward. Some retain a gently convex core which is not clearly demarcated from the walls (Fig. 4F, G), whilst others have a flat or gently concave posterior surface (Fig. 4I). In no case does a core persist when the depth of the posterior cavity exceeds 1 mm though the trace of a groove (Fig. 4H) or a difference in texture (Fig. 5J) may indicate the former presence of a core. For each of these variants, some folding on a hinge may have occurred (Fig. 4, side branches to right) and for the thinnest specimens, folding may be complete (Fig. 4L(1)). Presumably, frontal collapse occurred only when the form had become highly thinned; a possible example from Victoria is discussed below.

Many bowls thus appear to be independent of the button-disc series and to have developed by the obliquely backward growth of secondary glass constituting the walls. There would then be at least two developmental lineages of small australites which were distinct from the beginnings of aerodynamic shaping. A possible parental candidate for the bowl series is the button with strongly convex posterior profile of flange. Perhaps significantly, such buttons and elongated equivalents are common on Mt. Remarkable and Menangina Stations which have also provided many of the smaller specimens. It is easy to arrange a morphological series linking these buttons to cored bowls (Fig. 4D to G), but it cannot be assumed that such a series is also a developmental lineage.

There may also be a relationship between bowls and pseudo-discs as the result of frontal collapse of bowls. A specimen described and figured by Baker (1963 No. 12) may be interpreted as an example of extensive frontal collapse limited by a prominent flow ridge (Figs. 4L, L(2), 5E); other possible examples are Baker's Nos. 15, 20. Frontal collapse, like the dent in the top of a hat, requires that portion of a thin curved shape should be "turned inside out". In effect, it is a failure on a circular hinge, and the reason for it rather than for folding on a diametral hinge is probably seen in the ribbing provided by flow ridges or thickened edges.

Not only are the origins of bowls in doubt—and are perhaps multiple—but there is no precise definition of the form itself. The only natural

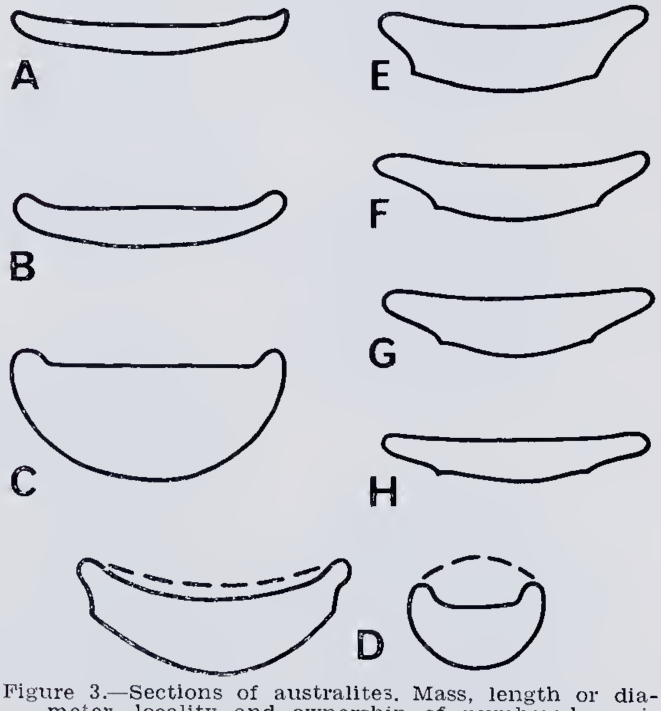

Figure 3.—Sections of australites. Mass, length or diameter, locality and ownership of numbered specimens are given in Table 1. A.—Tray-like form with incipient frontal collapse. No. 30, Table 1. B.—Tray-like form, mass 0.546 g, length 15.2 mm, Menangina Station, W.A. (WASM 10 613). C.—Broad oval of "massive" type, 0.231 g, length 7.3 mm, Earaheedy Station, W.A. (WASM 10 566). D.—Longitudinal and transverse sections of elongated form of "massive" type, profiles added to sections as broken lines. Right hand end of longitudinal section restored. No. 35, Table 1. E.—Thick form approximating to the plano-convex type. No. 11, Table 1. F.—As for E. No. 20, Table 1. G.—Plano-convex form, posterior cavity 0.2 mm deep. No. 23, Table 1. H.—Plano-convex form, posterior cavity 0.2 mm deep. No. 22, Table 1.

point of distinction would be when the posterior pole of the core was reduced below the level of the flange, but this distinction is not seen to have been uniformly applied in the literature. Fortunately, the somewhat artificial distinction between "small" flanged forms and discs has not been applied to bowls as an unnecessary complication.

Other general shapes are represented amongst small australites from Western Australia, though they appear to be rare in eastern Australia, or at least, unreported.

1. "Tray" forms which are thin and extensive with rim thickened by a flow ridge or by overflow of melt from the anterior surface to form a

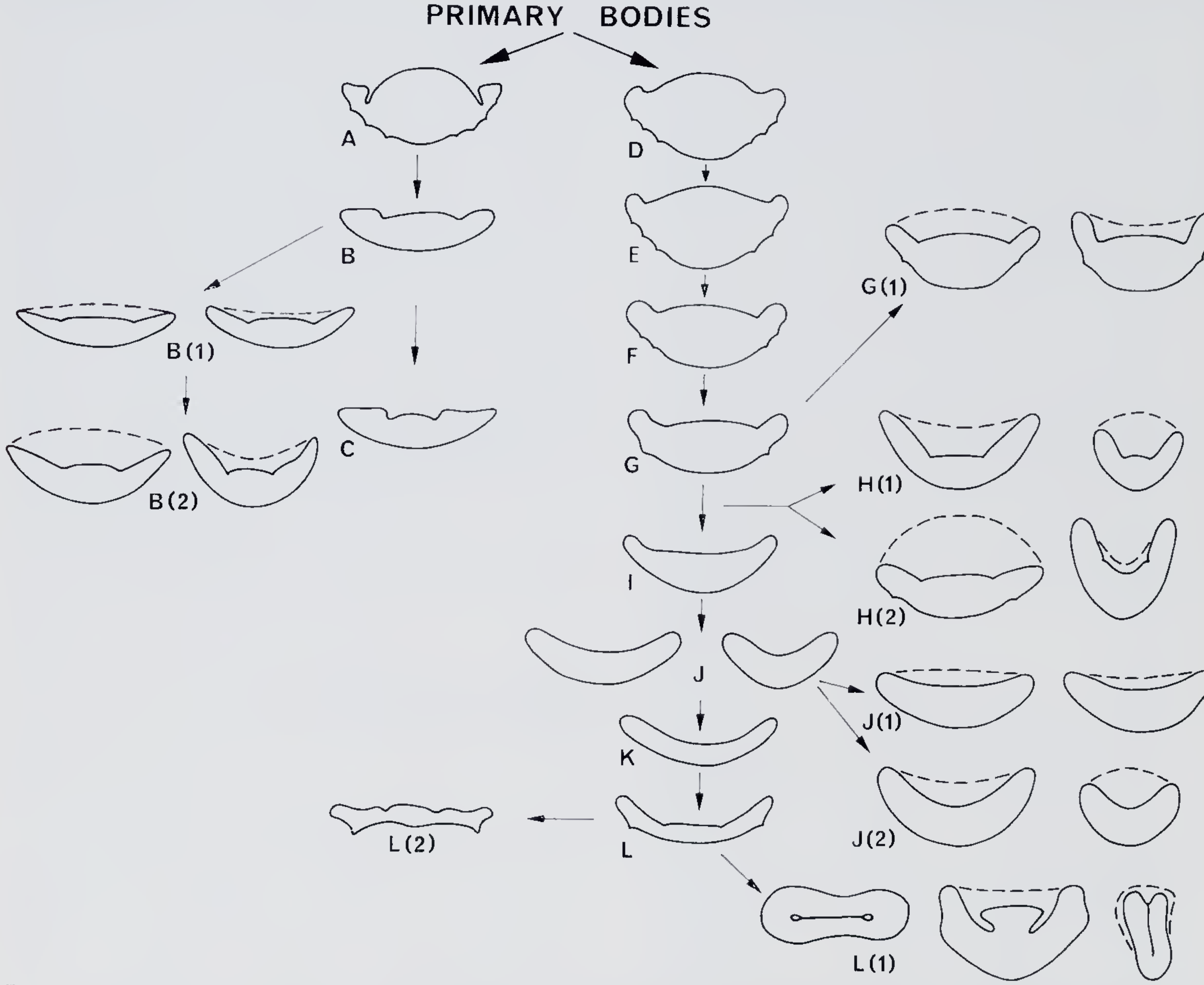

Figure 4.—Partial scheme of morphogenesis for small australites illustrated by vertical sections of uniform width to facilitate comparison, except that where two or more views are given, they are on the same scale for that particular specimen. Profiles of folded specimens added to sections as broken lines. Mass, diameter or length, locality and ownership stated except for specimens numbered 1-42, for details of which see Table 1. A.—Button with flat to concave posterior surface or flange, 2.74 g, 18.6 mm, Coolgardie W.A. (WASM 9465). B.—"Small" button, 0.146 g, 8.0 mm, Menangina Station, W.A. (WASM 10 613). B(1).—Longitudinal and cross sections of "small" button, very slightly folded, No. 2, Table 1. B(2).—Longitudinal and cross sections of "small" button or cored disc, gently folded. No. 1, Table 1. C.—Cored disc, 0.250 g, 9.7 mm, Port Campbell, Vic. (NMV E7830). D.—Flanged broad oval with convex posterior profile of flange, core emergent 1.5 mm above flange level, 1.82 g, 10.9 mm, Mt Remarkable Station, W.A. (KJ). E.—Button, core emergent 0.5 mm, 0.94 g, 11.9 mm, Mt Remarkable Station, W.A. (KJ). F.—Cored bowl, core 0.2 mm below flange level, 0.64 g, 11.2 mm, Mt Remarkable Station, W.A. (KJ). G.—Bowl, posterior surface faintly convex, No. 9, Table 1. G(1).—Longitudinal and transverse sections of a bowl, general type of G, gently folded, No. 10, Table 1. H(1).—Longitudinal and transverse sections of boat-shaped bowl with traces of outline of core, gently folded on longitudinal axis, No. 34, Table 1. H(2).—Round bowl with traces of outline of core, folding half completed, No. 7, Table 1. I.— Broad oval shallow bowl with concave posterior surface, 0.520 g, 11.0 mm, Menangina Station, W.A. (WASM 10 614). J.—Longitudinal and transverse sections of narrow oval bowl, No. 29, Table 1. J(1).—Longitudinal and transverse sections of round bowl (type of J) very slightly folded, No. 5, Table 1. J(2).—Longitudinal and transverse sections of narrow oval bowl (type of J) gently folded on transverse axis, No. 28, Table 1. K.—Longitudinal section of narrow oval bowl, No. 25, Table 1. L.—Restoration of highly thinned bowl shown in L(2) on presumption that it is frontally collapsed. Note prominent flow ridge. L(1).—Plan, longitudinal and transverse sections of completely folded thin bowl, walls 1.3 mm thick, gas escape tubules about half millimetre diameter, 0.358 g, 11.0 mm, Linton, Vic. (BM 1926, 316). Reference Dunn (1916). L(2).—Transverse section of frontally-collapsed, broad oval, thin bowl, now disc-like, 0.636 g, 14.5 mm, Port Campbell, Vic. (NMV E7821).

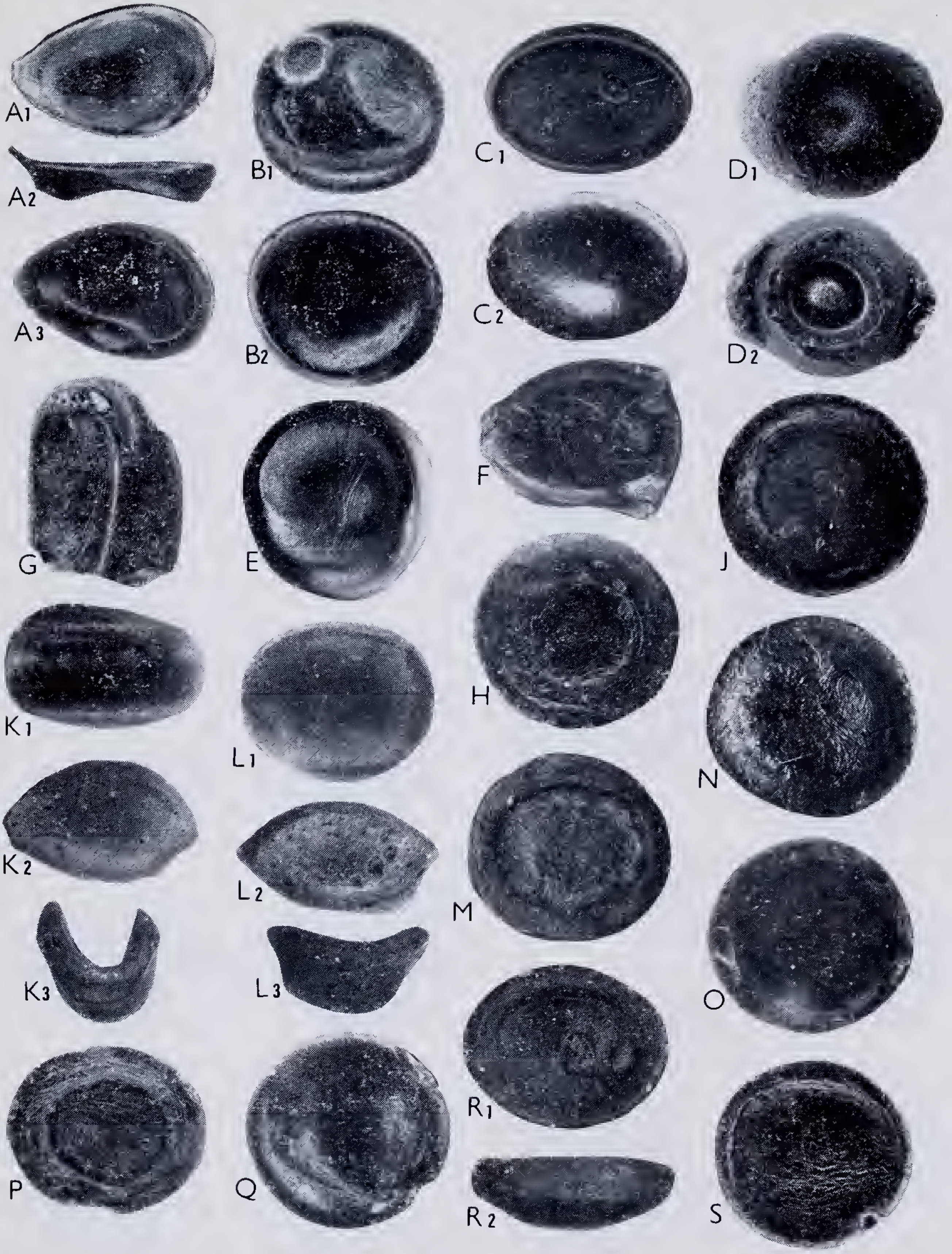

Figure 5.—Australites from Western Australia and Victoria. Illustrations are plan views (i.e. posterior surfaces of flight) unless stated otherwise. For details of specimens numbered 1-42, see Table 1. Scales vary slightly and may be judged by the dimensions given here or in Table 1. A1.—Teardrop bowl, length 13.4 mm, Menangina Station, W.A. (WASM 10 609). A2.—Side elevation of A1 showing frontal collapse. A3.—Anterior surface of A1 showing limitation of collapse by flow ridge. B1.—Broad oval, "tray" type, length 10.9 mm, Menangina Station, W.A. (WASM 10 614). B2.—Anterior surface of B1 showing frontal collapse. C1.—Narrow oval "tray" type, length 9.0 mm, Menangina Station, W.A. (WASM 10 609). C2.—Anterior surface of C1 showing frontal collapse. D1.—Anterior surface of fragment of hollow button, length 11.5 mm, Mt Remarkable Station, W.A. (KJ). Central collapse dimple over bubble cavity. D2.—Posterior view of D1 showing boss resulting from frontal collapse within breached bubble cavity. E.—Anterior surface of frontally collapsed broad oval bowl from Port Campbell, Vic. (NMV E7821). For details see Table 2. For transverse section see Fig. 4-L2. F.—Pine-seed form, length 10.6 mm, Earaheedy Station, W.A. (WASM 10 943). Flange broken from left end, overfolded at right end and fused to body which is visible through it. G.—Fragment of elongated "tray" type australite with thickened edge, length 9.0 mm, fold hinge along right-hand edge, i.e. right hand half of visible surface is anterior surface of flight. Mt Remarkable Station, W.A. (KJ). H.—No. 2. J.—No. 3. K1 to K3.—Plan, side and end elevations of No. 6. L1 to L3.—Plan, side and end elevations of No. 8. M.—No. 10. N.—No. 12. O.—No. 13 P.—No. 14. Q.—No. 15. R1 and R2.—Plan and side elevations of No. 16. S.—No. 18.

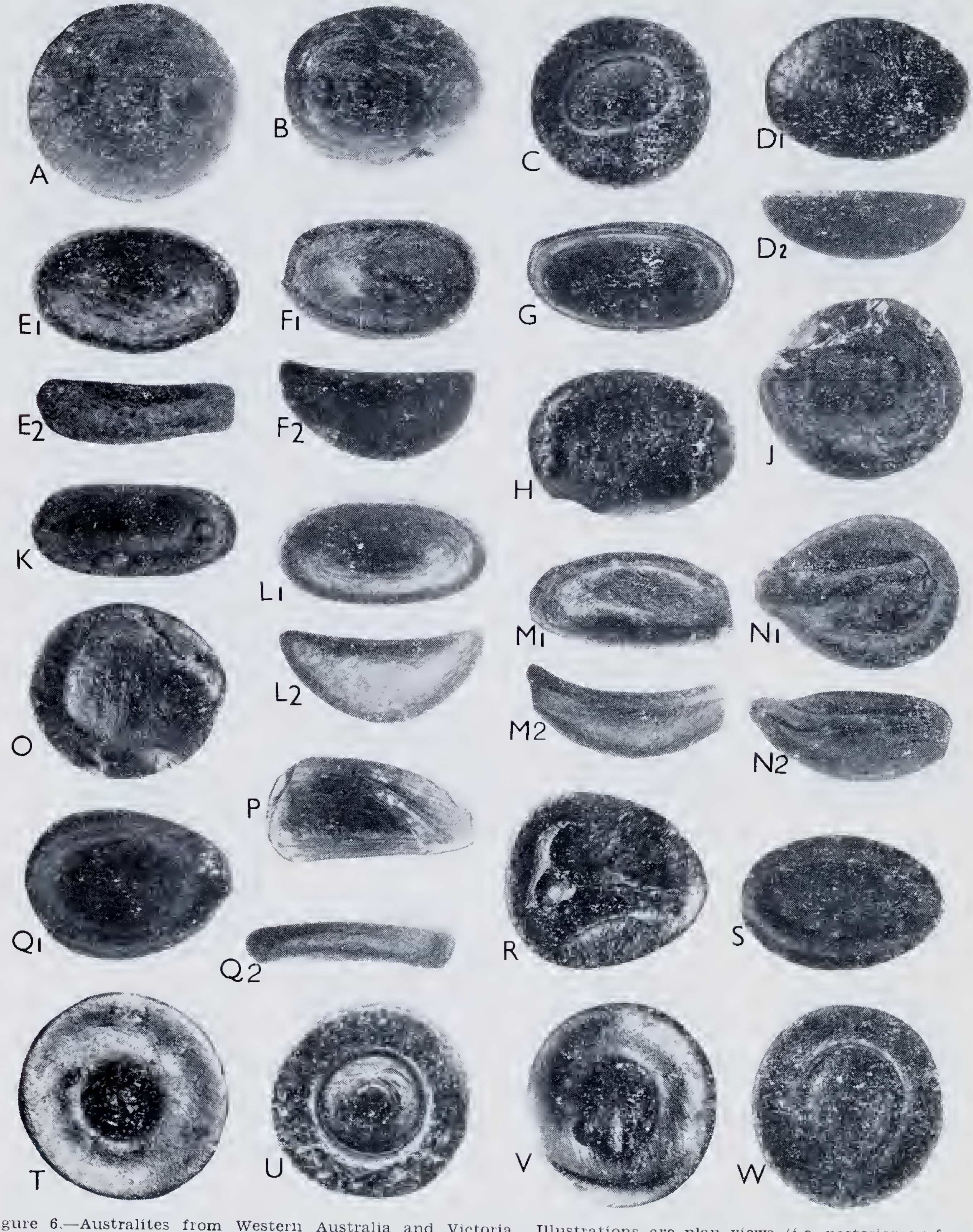

Figure 6.—Australites from Western Australia and Victoria. Illustrations are plan views (i.e. posterior surfaces of flight) unless stated otherwise. For details of specimens numbered 1-42, see Table 1. Scales vary slightly and may be judged by the dimensions given here or in Table 1. A.—No. 22. B.—No. 23. C.—No. 24. D1 and D2.—Plan and side elevation of No. 26. E1 and E2.—Plan and side elevation of No. 27. F1 and F2.—Plan and side elevation of No. 28. G.—No. 30. H.—No. 31. J.—No. 32. K.—No. 33. L1 and L2.—Plan and side elevation of No. 34. M1 and M2.—Plan and side elevation of No. 35. N1.—No. 38, showing overfolded tail fused to posterior surface. N2.—Oblique view of N1 showing hinge. O.—No. 39. P.—No. 40, showing thin, tapering, strap-like feature, possibly portion of overfolded tail, fused obliquely across posterior surface. Q1 and Q2.—Plan and side elevation of No. 41. R.—No. 42. S.—"Tray" form, length 15.2 mm, Menangina Station W.A. (WASM 10 613). T.—Cored disc, Port Campbell, Vic. (NMV E7830). See Table 2. U.—"Small" button, Menangina Station, W.A. See Pair 1, Table 2. V.—Teardrop plate with oval flange, Port Campbell, Vic. (NMV E7837). See Table 2. W.—No. 36. See also Pair 3, Table 2.

low wall around the posterior surface. The posterior surfaces are flat or gently concave (Fig. 3A, B, 6S). Frontally collapsed examples are shown in Figure 5B, C and a folded example in Figure 5G.

2. "Massive" forms with tray-like top, having a stout body and also showing the low posterior wall formed from overflowed melt (Fig. 3C). These also include elongated examples such as that having the general form of the swingboat of the fairground (Figs. 3D, 6M).

3. Very shallow bowls with outwardly-directed secondary growth, sometimes approximating to plano-convex form (Figs. 3E-H, 6A, B).

The relationships of these forms to the commoner small forms are not evident. It is tempting to see significance in the absence of well-developed discs of the type found in Victoria and the presence of these other forms in Western Australia in contrast to almost the opposite situation in eastern Australia. However, I have noticed a broad oval specimen of "Type" 1 and a round specimen of "Type" 2 amongst South Australian specimens. More likely, the rigorous weathering and erosion in interior Western Australia coupled with a lack of reporting of eastern Australian examples of the other forms are responsible.

A further minor mystery concerning small australites is that all the major plan-view shapes of larger australites are represented except the dumbbell. No "small" flanged dumbbells, dumbbell plates or bowls are present amongst the specimens examined. Nor do they appear to have been reported from elsewhere. It is suggested that the prominence of the gibbosities rendered them especially liable to ablation losses and that the typical shape was lost when size reduction was severe. It has been noticed that even specimens of mass 10 g are sometimes boat-shaped in plan view, though still showing a dip in the posterior profile as seen in side elevation, an indication of their derivation from dumbbell primary bodies.

Conclusions

A scheme of morphogenesis for small australites with two main lineages and side branches resulting from folding is presented in Fig. 4. Eastern Goldfields examples have been used in illustration if available. The scheme should be regarded as a summary of some of the suggestions which have been made and tentative in the extreme.

The range of posterior profile of flange from strongly convex to concave is related to increasingly severe deceleration (Chapman 1964). The two lineages of small australite development should perhaps be regarded as the ends of a whole spectrum of behaviour. The plano-convex type is a possible intermediate lineage.

No apology is offered for not having solved the problems of small-australite morphogenesis as a result of examining some weathered specimens from the Eastern Goldfields. The dearth of material and the considerable variety within that which is available leave the student groping for a pattern. What are presently "missing links" in morphological series may be found. Though there appear to be continuous button-disc and button-bowl morphological series, each individual is the final product of a different combination of size of primary body, entry velocity, incident angle or other variable. A morphological series of different individuals is not necessarily a developmental series. For example, there can be no certainty that a cored disc evolved through the "small" button form which, for a different primary body, was the final form. The true "missing links" of development will be forever missing because they had only a transitory existence during flight. The sectioning of some specimens for examination of the internal flow lines might well be informative but destructive examination of this rare material has thus far been avoided. It remains true as it was prior to this study that the collecting and recording of more small forms is needed before their types can be more clearly defined and a comprehensive scheme of morphogenesis can be proposed with any degree of confidence.

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